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SURVEY OF BIOSCIENCE PROBLEMS AT BUDOCKS ACTIVITIES

By

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ABSTRACT

The U. S. Naval Civil Engineering Laboratory has been review~~ing~~ bioscience-oriented problems at field activities. of the Bureau of Yards and Docks. The primary purpose of the Bioscience Study is to ascertain if specific biological research is justifiable on the basis of its contribution to the Bureau's mission. Another objective of the study is to determine if there are areas of biological investigation that should be pursued, ~~at the U. S. Naval Civil~~ Engineering Laboratory; and, if so, to delineate those areas. Information for the study was gathered principally from Bureau of Yards and Docks field activities, government laboratories, marine biological laboratories, and universities. It was concluded that several of the many diverse functions under jurisdiction of the Bureau of Yards and Docks are in areas in which biological research might contribute significantly. Major areas in which research is recommended are biodeterioration of engineering materials, harbor pollution, biological oceanography, and marine biotechnology.

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INTRODUCTION AND STATEMENT OF PURPOSE

The U. S. Naval Civil Engineering Laboratory has been reviewing bioscience-oriented problems at field activities of the Bureau of Yards and Docks. The primary purpose of the Bioscience Study is to ascertain if biological research is justifiable on the basis of its contribution to the Bureau's mission. Another objective of the study is to determine if there are areas of biological investigation that should be pursued at the U. S. Naval Civil Engineering Laboratory; and, if so, to delineate these areas.

SCOPE AND METHOD OF APPROACH

It was immediately apparent that the Bioscience Study would take the form of an exploratory survey. An initial consideration was the establishment of criteria for determining the extent of Laboratory commitment within specific areas of research. It was concluded that the first and most basic criterion is the relevancy of that research to current or future problems at Bureau of Yards and Docks Activities. The scope, magnitude, and likelihood of success of investigations underway at other institutions and the anticipated cost of the specific research are also deemed important criteria.

GATHERING INFORMATION

The authors secured information for this reivew from NCEL reports, other government publications, and the open literature. They visited field activities of the Bureau of Yards and Docks, government laboratories, marine biological laboratories, and universities; and communicated with other institutions by mail. Although information from field activities of all naval districts is desirable, time and funds permitted only cursory survey at a few selected activities. The authors visited Bureau of Yards and Docks Activities in the First, Third, Fifth, Eighth, and Eleventh Naval Districts, U. S. Army Natick Laboratories, the Woods Hole Oceanographic Institution, the Clapp Laboratories, the U. S. Naval Applied Sciences Laboratory (BUSHIPS), the New York City Aquarium, the Lamont Geological Observatory, the University of Southern California, the Naval Missile Center, and the Southern Forest Experiment Station (USDA). A

detailed list of the individuals, activities, and institutions contacted is found in the Appendix of this report.

Shortly before visiting the field activities of the Bureau of Yards and Docks, the Laboratory representative prepared and mailed "Study-Forms" or questionnaires to the field activities so as to acquaint them with the type of information desired. The study-form sought statistical information that would permit a comparison of relative magnitude of problems at various geographical locations. However, such statistical data as the length of conduit maintained, the number of piles driven each year, the life-span of a given engineering material, or the amount of funds annually expended for a given maintenance procedure are not readily available at the field activities and can be gathered only at considerable expense. The available information consisted of case histories of specific structures and personal experiences or opinions of individuals at the activities.

FINDINGS

Functions under the jurisdiction of the Bureau of Yards and Docks are of great scope, diversity, and magnitude. With sixty thousand civilian and military employees (and many workers hired under maintenance contracts) and with an annual budget of about 600 million dollars, Public Works Activities of the Bureau maintain and provide services for a twenty-one billion dollar (exclusive of land) complex of buildings, equipment, facilities, and waterfront structures.[1] They maintain 104 thousand buildings, five and one half million square yards of docking facilities at the one thousand Navy piers and wharves, 130 miles of seawall, 187 miles of fender system, 27 hundred miles of liquid-fuel lines, 44 million barrels of storage facilities for fuel, 126 million square yards of airplane runways and pavements, 128 million square yards of street and roads, 22 major steam plants, 9 domestic water treatment plants, 14 major sewage treatment facilities, and other facilities too numerous to itemize. Other activities of the Bureau of Yards and Docks are currently engaged in an expanding program aimed at increasing the capabilities of the Navy in undersea construction. The Bureau of Yards and Docks also shares with other branches of the Department of Defense in the management of 27 million acres of land. Several of the many and diverse functions performed by the Bureau of Yards and Docks and its field activities, including several of the functions enumerated above, are in areas in which biological research might contribute significantly.

Biology of the Deterioration of Engineering Materials

It appears to the authors that the deterioration of engineering materials is by far the costliest problem confronting the Bureau of Yards and Docks. The Bureau allocates approximately 300 million dollars annually for the maintenance and repairs of structures and utilities damaged by processes of wear and deterioration. Maintenance and repair, however, constitute only part of the huge cost of deterioration; for much, if not most, of the approximately 250 million dollars allocated to the Bureau for military construction is, in the ultimate analysis, replacement construction. Furthermore, repair contracts for more than $10,000 are frequently paid for from military construction funds. Another factor, the cost of which is difficult to ascertain, is the loss of effectiveness of the Naval facility when closed for repairs and reconstruction. If paint, wood, concrete, steel, and asphalt did not deteriorate, the Bureau of Yards and Docks could probably operate on half of its present annual budget of nearly one billion dollars and could provide more efficient services for the fleet.

It is difficult to determine the expense of deterioration attributable to biological processes, for the deterioration of engineering materials occurs as a result of complex, little-understood, and intertwined biological, chemical, and physical processes. Biochemical deterioration is especially difficult to distinguish from spontaneous chemical deterioration. It is thought that paint and asphalt may frequently deteriorate in consequence of photochemical processes in which microorganisms play no role. Metals, however, are the only engineering materials whose deterioration at ordinary temperature has been proven to occur in an environment free of microorganisms. On the other hand, there is ample proof that the deterioration of wood is caused by macroorganisms or microorganisms, that the anaerobic corrosion of iron is caused by bacteria, and that the mildewing of paint is caused by fungi. There is also incomplete evidence that the deterioration of other engineering materials is influenced by the metabolic activities of microorganisms, and it is well known that thousands and even millions of microorganisms inhabit every square millimeter of every surface of almost every structure and object. Were the earth devoid of microorganisms, many engineering materials would probably not deteriorate at a perceptible rate, just as food stored in a sealed can does not spoil nor does the interior of the can rust unless air or bacteria are admitted.

Navy-sponsored Research on the Biological Deterioration of Materials. Because the Bureau of Yards and Docks faces deterioration problems of such great scope and magnitude, it should be vitally concerned over the adequacy of research efforts in that area. Hence, a brief survey of Navy-sponsored research on the prevention of deterioration is in order.

The expenditure of the Office of Naval Research in FY64 for research in the material sciences[2] was $4,471,000. Approximately $772,000 was allocated to corrosion, deterioration, and surface protection studies. This amount included $225,000 for the publication of the "Prevention of Deterioration Center Abstracts," a publication which was recently discontinued. Approximately $130,000 of the funds for deterioration and surface protection studies were allocated to the Naval Research Laboratory for studies of biodeterioration. The latter funds were designated primarily for field studies of tropical deterioration at exposure sites in the Canal Zone and at Panama. Biodeterioration studies at the Naval Research Laboratory have been curtailed considerably in recent years.

Similarly, the Office of Naval Research sponsors studies in the biological sciences,[3] an investment in FY64 of six million dollars. Of this amount, approximately $70,000 was allocated to various universities and marine biological laboratories for studies on fouling or on the deterioration of materials.

The Bureau of Ships sponsors but slight amount of research on the biological deterioration of materials, a project at the U. S. Naval Applied Science Laboratory on anti-fouling paints and one concerning bacterial corrosion of metals in the deep ocean. The two investigations involve a total annual expenditure of two or three man years of effort.

For a number of years the Bureau of Yards and Docks has sponsored investigations at U. S. Forest Service Laboratories on the deterioration of paint and wood. The program is fairly extensive and probably involves the annual expenditure of four to eight man years of effort. The research on wood deterioration at the U. S. Forest Service Laboratories has been outstanding and most productive; though recently three or four of the leading investigators associated with the project have been transferred to other organizations, have retired, or will soon retire.

Dr. A. F. Verrall of the Southern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, New Orleans, Louisiana (the field station is located at Gulfport, Mississippi) is both a wood technologist and a plant pathologist. He has devoted most of his long career to studies of the effects of moisture on wood and paint. His field observations and studies, many of which were conducted for the Bureau of Yards and Docks, have included both military and non-military structures in continental United States, the Panama Canal Zone, and various Islands of the Pacific Ocean.

Dr. Theodore C. Scheffer of the Forest Products Laboratory, who frequently collaborates with Dr. Verrall, has devoted several years to an exhaustive survey of the deterioration of wooden buildings at Naval activities. The results of his study were presented to the Bureau in a long report filling several volumes and containing hundreds of photographs. Only a few typewritten copies of the report were made and none are now available for distribution. Dr. Scheffer and Dr. Verrall are, however, currently summarizing their field observation and research studies on Naval Structures in an overall report for the Bureau of Yards and Docks. It is recommended that the report be given wide distribution to Public Works Activities.

The work of Dr. Verrall[4,5,6,7,8] and his associates is well known to a few of the Special Assistants for Applied Biology within the Districts, though it is not as well known as it should be to the design engineers and maintenance personnel at Bureau of Yards and Docks Activities. A few of the more significant findings of the Forest Service scientists are given in the following paragraphs.

a. Even in damp climates, properly cured wood is not subject to fungus decay unless it comes in contact with "liquid" water. In warm climates, rain is usually the principal source of liquid water affecting wood. In cold climates or in refrigerated buildings, however, condensation is often more important than rain.

b. Similarly, paint covering a wooden surface ordinarily does not rapidly deteriorate unless it comes in frequent contact with liquid water.

c. The design of the roof is the most important single factor influencing the deterioration of wooden buildings. The life of the paint and the wood are both directly related to the length of the roof overhang. In rainy climates the roof of a one-story building should have a two to five foot overhang. Two story buildings should be built with a canopy protecting the siding of the first story.

d. An inexpensive dip-treatment in an oil-borne water repellent preservative solution improves the decay resistance of lumber and prolongs the life of paint applied to it. If old paint is removed from an in-place wooden surface, the application of a water repellent preservative prior to repainting, prolongs the life of the paint and reduces decay. On several wooden buildings of the U. S Forest Service, where only oil-borne water repellent preservative are used, maintenance without painting is quite satisfactory. An oil soluble pigment is added to help camouflage dirt, but pigment cannot be added to cover dirt as it interferes with penetration of oil-borne preservatives.

For a number of years, the Bureau of Yards and Docks has sponsored an extensive program of research on marine borers at the U. S. Forest Products Laboratory in Wisconsin, the Clapp Laboratories in Massachusetts,[9] the University of Miami, Florida,[10] and the U. S. Naval Civil Engineering Laboratory, Port Hueneme, California,[11,12,13,14,15] and these investigations have been instrumental in the development of new standards for the purchase of marine piling.[16,17] Personnel at field activities of the Bureau of Yards and Docks hail the standards as a significant contribution in the campaign against marine borers. Several promising new preservatives[12,13] for marine piling have been discovered as well as causes for the breakdown of creosote in the marine environment.[14] The latter information might lead to the development of creosote-containing mixtures that will not deteriorate. Another achievement of marine borer research has been the accumulation of copious information on the distribution of boring organisms[9] which is useful for predicting borer activity in various harbors and the consequent planning of construction in these harbors. Marine borer research has also led to the development of analytical methods for evaluating the quality of wood preservatives.[15] However, the marine borer studies have been curtailed and will be phased out at NCEL by FY67.

In summary, the various Bureaus and Offices of the Navy sponsored approximately $1,000,000 worth of research annually on the deterioration of materials. Of this amount approximately $300,000 is for studies of biological deterioration and marine fouling and most of the latter is for field exposure tests or field surveys. Less than $50,000 is allocated to universities for basic research. Compared to the magnitude of its total research effort and the magnitude of its problems with deterioration, the Navy's research effort on the prevention of deterioration, especially biological deterioration, is not large. Year by year the effort in this area becomes smaller though the economic importance of deterioration rapidly increases.

Deterioration of wood by fungi and insects. It is frequently stated that the use of wood as a structural material is declining. This is certainly not evident to one who visits Naval Shore Establishments within the United States where wood is, by far, the principal structural material employed. The great majority of warehouses, shops, office buildings, quarters, etc. are constructed of wood. According to Kenneth E. Wright,[18] Head, Civil Engineering and Specification Section, Bureau of Yards and Docks, the Bureau's purchase of lumber was in excess of $10,000,000 in 1963. This expenditure included only contract construction; not wood products procured through public works centers for maintenance, repairs and similar projects, nor labor costs for the erection of wooden structures.

The deterioration of wood by fungi and insects is a moderately severe problem at all of the Navy districts in the continental United States, and even more severe at Naval Districts located in tropical areas. The authors did not visit Naval Activities in tropical areas, though they ascertained from other laboratory personnel visiting those areas that fungi and termites cause very extensive damage to wooden structures. The structures most commonly affected are buildings, utility poles, and waterfront structures, though all items or structures made of wood or cellulose regardless of their location are subject to attack by fungi and insects.

Insect and fungus decay of Navy buildings in continental United States is usually confined to small areas within some buildings. Termites are generally discovered and exterminated before they cause extensive damage, and occasional replacement of a few boards or timbers suffices to repair the damage. Fungi, on the other hand, are responsible for considerably more damage; but at Naval Bases in the continental United States, the repair occasioned by fungus decay is also usually limited to the periodic replacement of a few boards and timbers at scattered locations throughout the buildings. Buildings are commonly abandoned before they reach the stage of deterioration where more extensive maintenance repair is required. It is difficult to estimate the dollar value of the damage inflicted on Navy buildings by termites and fungi because in-house carpenters usually perform the many minor repairs required in consequence of that damage.

Frequently fungus-decay of refrigerated or air-conditioned buildings is not confined to small areas. Last year, for example, it was necessary to replace an entire side of the cold storage building at Corpus Christi Naval Air Station because of fungal activity (Figure 1). Extensive repair of several other air conditioned and refrigereated buildings has also been required in recent years at various Naval bases and stations.

Wooden structures whose roofs fail to shed water frequently are severely damaged by wood-decaying fungi (Figure 2). A large Navy-owned building leased to the Todd Shipyard Corporation, New Orleans Division, Louisiana, is a classical example. The building, a "plate shop" (Figures 3 and 4), is still used though its roof and sides are falling apart. The failure can be traced to the inability of the roof and eaves to keep interior walls and inner roofs boards dry. The "plate shop" constructed in great haste during World War II, was to have been an all steel and glass building large enough to house a ship. Though a heavy steel framework was erected, it was covered with substitute material because of wartime shortages. A wooden roof was fastened to the steel framework and no overhang was provided. The frames and sashes of the many windows, which covered more than half of the building, were also constructed of wood. On the sides, two, 2" x 4"

nailers were fastened to the steel framework as a footing for a two-ply layer of 3/8" gypsum board. The gypsum plaster was bonded to heavy paper and then covered with asbestos shingles.

The absence of a roof overhang proved disasterous. Only a small rain gutter prevented rain from reaching the gypsum board, and soon after construction, water reached the paper to which the gypsum plaster was bonded. The paper proved to have low wet strength and, in consequence, the gypsum board lost its ability to anchor the asbestos shingles. Water also reached the edges of the roof, the wooden joists, and the window frames, thereby accelerating fungus decay. Gaping holes now exist on the east and west sides of the building, and many of the windows are falling out. Inspite of the poor choice of backing for the gypsum plaster, the building would perhaps have held up had an adequate roof overhang been provided and had the roof boards, joists, and windows frames been dip-treated in a water repellent preservative.

Many of the buildings at the Headquarters Support Activity, New Orleans, Louisiana, have already been razed, and those that remain have reached the stage of deterioration where maintenance is not economically prudent. Nearly all of the wooden buildings have been covered with asbestos shingles; but window frames, steps, garage doors, exterior trim, etc. remain exposed to rain and require periodic painting and repair. Decay extends to the interior framework of those buildings whose roofs leak. The majority of the buildings are not being used but are being maintained on a stand-by or reserve status and it is anticipated that many of them will be condemned within a year or two. Nevertheless, the buildings still serve to dramatically illustrate deterioration problems at a Naval activity.

Insects and fungi cause considerably more damage to Navy buildings within tropical areas than to Navy buildings in continental United States. Termites breed so rapidly in tropical areas that expensive fumigation is necessary to eliminate them, and in a few years, reinfestation occurs and fumigation must be repeated. Termites can be found crawling freely over the floor of most wooden buildings at tropical Navy bases, and many of the buildings are destroyed within twenty years. Though lumber is stored well above ground, much of it may be infested with termites even prior to construction.

Wooden utility poles at U. S. Naval Bases usually deteriorate even more rapidly than wooden buildings. The poles, used for a variety of such purposes as suspending antennae, telephone lines, and power lines, are unprotected by roofs and hence they are exposed to the adverse effects of the elements. Thus deterioration occurs at a relatively rapid rate. Records of the life spans and replacement costs of the poles are apparently

not readily available though replacement is reported to be frequent and costly. Even in temperate areas many poles fail in ten years and in tropical areas failure frequently occurs in five years. According to reports received at NCEL from the field, creosote is often not an effective preservative for utility poles in hot, humid climates.

Although marine borers are the agents most frequently associated with deterioration of wooden waterfront structures, fungi, and insects are also responsible for considerable damage (Figure 5). The surfaces of piers and wharves exposed to the weather and to contamination by bird droppings are conditioned and prepared for the entrance and growth of wood-eating insects and wood-decaying fungi.

The wharf at the Headquarters Support Activity, New Orleans, Louisiana, provides an excellent example of a waterfront structure damaged by insects and fungi. A wharf, elevated about twenty feet above the normal water level, extends the entire length of the approximately one mile of river frontage of the activity. Attached to the wharf for a considerable portion of its length is a wide deck upon which several of the principal buildings are located. A several hundred foot section of the wharf is constructed on huge concrete filled steel cylinders and is decked with reinforced concrete. The remainder of the wharf and the deck on which the buildings rest are built on creosote impregnated wooden piles. Half of the wharf, including the section constructed of concrete and steel, is leased to the Todd Shipyard Corporation. The remainder is maintained by the Navy, much of it on a stand-by or reserve status, and about 800 feet of the wharf are now being used for berthing Navy-owned vessels. Plans and designs for rebuilding the latter 800 foot section have been completed, but funds for the project have not yet been appropriated.

The portion of the wharf constructed of concrete and steel is relatively new and is in excellent condition, but the wooden portions have been extensively damaged by fungi and termites. Even the wooden fender piles abutting the concrete portion of the wharf have been partially destroyed and decay has so damaged one section of the wooden wharf that is has collapsed, presumably from the strain of a heavy piece of machinery moving over the weakened deck. The creosoted outer shells of the piles supporting the wharf deck and adjoining building deck are still solid and intact though core samples of the interior of the piles disclosed that the heartwood is at least partially, and in many instances completely, destroyed by fungi and termites. (The piles are free of Limnoria and Teredo attack as marine borers cannot live in fresh river water.) The decking has also been extensively attacked by fungi and termites. Replacement of the creosoted deck lumber has been so extensive that is is improbable that many of the original deck boards remain. The Todd Shipyard Corporation replaces over a thousand board feet of deck timber annually on its portion of the wharf. (Frequently replacement of deck lumber is also required at other Naval Bases, as for example, at San Diego.)

Other examples of waterfront structures affected by fungi and insects are pier decks at submarine bases. Creosote-treated wood cannot be used on these decks as creosote might be carried into the submarine on the shoes of the men, thereby contaminating the submarines interior atmosphere. This problem occurs at the submarine base at Groton, Connecticut, where wood-rotting fungi destroy the untreated decking and necessitate replacement every three of four years (Figure 6). Economically the problem is not large enough to warrant a major Laboratory investigation, however, the problem is important as replacement of the deck interferes with operation of the submarine fleet.

Termites and fungi by no means limit their activities to the destruction of buildings, utility poles, and waterfront structures. Furniture, paper, and any items made of wood or cellulose are subject to attack by fungi and insects. At Naval activities in tropical areas, office furniture and office files are periodically sterilized with heat to prevent their decay. Clothing is stored in heated lockers. Wooden frames of vehicles and trailers at Guam sometimes rot completely in eighteen months and methods are being sought to protect them from fungus decay and insect attack.

Destruction of piling and timbers by marine borers. Although concrete and steel are now the materials of choice for many major waterfront structures, wood is still essential. Bearing piles such as those supporting quay walls are frequently wooden as are fender systems of almost all Navy piers and wharves; and wooden groins, jetties, dolphins, and sea walls are also widely used. Approximately fifteen percent of the existing piers and wharves are constructed wholly of wood, and occassionally wood is still used for the construction of small piers and wharves.

According to data presented at the 1963 Cooperative Marine Borer Training Course at Duxbury, Massachusetts, the Navy maintains more than 5 million square yards of wharves and piers. Data presented at a Wood Preservation Technical Seminar, October 23, 1963, at Brooklyn, New York, indicated that, on the average, 5.64 yards of the wharves and piers in the Third Naval District provide one linear foot of berthing. If the same average held for other Naval Districts, the total berthing facilities maintained by the Navy (i.e., the total length of fender system) would be nearly one million linear feet or approximately 187 miles, (Table I). Based on the assumption that fender piles last for an average of ten years and that six miles of fender system can be placed for $1,000,000, the estimated total cost for maintaining only the fender system of the Naval Shore Establishment is around $3,000,000 annually.

Table I. Inventory of Major Waterfront Structures Owned by Navy

Piers	Concrete	Wood	Wood and Concrete	Steel	Total
Number	309	292	21	113	735
Thousands of square yards	1,503	684	92	2,080	4,359
Berthing in thousands of feet*	266	121	16	369	773
Estimated miles of fender systems*	--	146	--	--	146
Wharves:					
Number	97	75	11	62	245
Thousands of square yards	376	202	103	537	1,218
Berthing in thousands of feet*	67	36	18	95	216
Estimated miles of fender system*	--	41	--	--	41
Sea Walls:					
Number	127	42	7	146	322
Thousands of linear feet	271	65	37	320	693

*Estimated from the number of square yards.

Limnoria attack is relatively severe in most harbors of Southern California (Figures 7 and 8). For example, at the U. S. Naval Station, San Diego, California, fifteen concrete piers with wooden fenders and camels were installed in 1953. Ninety-three of the 1,250 fender piles of these piers required replacement in 1961. At present 268 more need to be replaced because of severe damage by Limnoria at the water line and by fungus decay and other organisms above the high tide line (Figure 7). At all of the seven major Naval activities in the San Diego harbor there are 11½ miles of wooden fender piling valued at $2,000,000 and 50 wooden dolphins valued at $350,000. The fender piles must be replaced on the average of every twelve years in the north bay and every seventeen years in the south bay. On the basis of these figures, it is estimated that 4,000 feet of fender systems needs to be replaced each year at an average cost of $125,000. These figures are probably low as costs are now higher than they were at the time of installation and the estimates of twelve and seventeen years for the life of fender systems are two to five times longer than the estimates generally obtained at other Navy bases. Furthermore, marine borer activity in the San Diego Harbor will probably increase when harbor pollution is abated.

Wooden piers and wharves at gulf ports such as Houston and Galveston last last for about fifteen years. They are being replaced by piers constructed with steel H-beams and concrete decks, and only fender systems of the new piers are constructed of wood. The new fender systems are not being constructed with driven piles but with sawed timbers fastened to the steel H-beams and extending only a few feet into the water. The suspended timbers can be examined and replaced more easily than can driven piles. Information on the frequency of fender timber replacement is not readily available but it can be assumed that they must be replaced much more frequently than the piers and wharves.

Limnoria attack is generally very slight and teredine borer attack is commonly moderate in the heavily polluted waters of east coast harbors. Properly creosoted timbers last indefinitely at all save the southermost of the east coast harbors, as is evidenced by the great number of wooden piers in the Third Naval District that are in good condition after decades of service. However, replacement costs for untreated fender piles are great at some of the Naval activities on the east coast. At Norfolk Harbor, for example, over three thousand fender piles were replaced in 1963 (one out of every three or four fender piles) by a full-time crew of twenty-one men. At Newport and Quonset Point, Rhode Island, where untreated piles are also commonly employed for the fender system, it is reported that the typical fender pile is replaced in three to six years.

Limnoria attack is very slight but teredine borer attack can be severe in cold water harbors such as Kodiak, Alaska. In tropical harbors such as Pearl Harbor, Quantanamo, and Panama, both Limnoria and teredine borer attack is severe and even well creosoted timbers frequently fail in as short a period as five years.

Many different timbers such as pine, fir, white oak, red oak, gum, cypress, eucalyptus, and greenheart are employed as fender piles at various Naval activites. Both preservative-treated and untreated timbers of the same varieties of wood are employed; and the costs of the various timbers, their structural strength, their marine borer resistance, and their service life vary tremendously. With the exception of greenheart piles, the cost of driving and pulling is perhaps higher than the cost of the timbers themselves; nevertheless, the cost of the timbers is not trivial and a study of all factors would be required before a decision could be made concerning the overall economics of timber species and preservative treatment.

In several of the coastal states, timbers are produced that are not suitable as saw timbers but that are of fender-pile dimensions. Seldom are these low priced timbers treated with chemical preservatives as most of them are of species that cannot be satisfactorily impregnated. Their purchase has the advantages of remarkably low initial cost and shipping charges and enhanced goodwill of the local community. However, the service life of fender piles appears to be rather short at several Naval activities employing locally produced timbers. Therefore, even though expedient for local diplomacy, the purchase of locally produced timbers may not always be to the economic advantage of the Navy.

The common argument favoring the use of untreated timbers for fender piles is the statement, which has not been fully verified, that fender piles are usually broken by ships before they can be damaged by marine borers. There are, however, many reasons to doubt the accuracy of this statement. For example, in most harbors untreated pine or fir normally succumb to marine borer attack in less than a year's time. Other species of timbers may have a little more resistance to marine borer attack than pine or fir, but there are no evidences indicating that common North American timber species possess any substantial degree of marine borer resistance. Furthermore, creosote-treated pine and fir fender piles at San Diego last for an estimated average of twelve to seventeen years and then require replacement primarily in consequence of marine borer damage. A survey at several east coast Naval activities employing untreated fender piles disclosed that three to five or six years is probably a maximum life period for the untreated piles. Damage by ships is blamed for the short life, but an examination of a limited number of piles removed from

these harbors disclosed severe marine borer attack. If ship damage were indeed the cause for the unusually short life of fender piles at east coast harbors employing untreated timbers, one would arrive at the unlikely conclusion that the seamanship of the Atlantic Fleet is of decidedly lower calibre than the seamanship of the Pacific Fleet. Thus, it cannot be stated *a priori* that fender piles require replacement primarily in consequence of ship damage.

In view of the large and variable costs for the maintenance of fender systems throughout the Navy, and that the operation of the fleet is impeded when a pier is closed for repairs, it is evident that the fender system problem is an area that requires investigation. The investigation would not necessarily require laboratory effort but would require that records be established that would make comparisons possible. A similar study was made by the New York Port Authority who concluded that creosoted red oak was the most economical material for fender piles in the New York Harbor.

The fender pile problem is not the only problem associated with marine borers. As previously enumerated, considerable wood is still employed for the construction of other waterfront structures. Concrete and steel are, to a considerable extent, replacing wood for the construction of piers and wharves, but it is by no means established that the latter materials will prove superior to wood. (The problems associated with the use of concrete and steel for waterfront structures will be discussed in a later section of this report.) Effective means of reducing or preventing destruction of wood by marine borers are still sorely needed.

Microbiological deterioration of paint, coatings, and plastics. The amount of money spent by the Bureau of Yards and Docks for painting and coating various interior and exterior surfaces is of considerable magnitude. In a recent article in the Navy Civil Engineer,[19] Mr. Alfred B. Moe, Manager Maintenance Engineering Branch, estimated that the Bureau of Yards and Docks' annual painting bill is well in excess of five million dollars. The authors concluded that painting costs at Naval Shore Establishments may be even greater than estimated by Mr. Moe.

In the New England area it is necessary to paint exterior surfaces on a three-year schedule, and even this is not frequent enough for the surfaces of wooden structures frequently show severe deterioration when periodic repainting is due. Annual costs of painting at the Groton Submarine Base alone is approximately $300,000. The Public Works Office employs twenty-one painters on a full-time basis, and, in contrast, hires three pest control operators and has no full time employee crews for repairing wooden waterfront structures or for mending asphalt roofs and

pavements. At this activity, the annual cost of repairs to waterfront structures and asphalt pavements are each approximately ten or twenty thousand dollars. It must be pointed out, however, that Groton does not have as many waterfront structures as Norfolk, San Diego, Pearl Harbor, and other major Naval bases. Furthermore, marine borers are not very active at Groton and ship damage to fender piles is negligible.

Annual expenditures for painting in the Atlantic Division are several million dollars. Most of this work is let out on contract. In contrast, annual expenditures for the repair of fender systems in the same division is approximately \$600,000. The latter estimate is based on the assumption that the entire division employs 40 men to repair fender systems at an average annual cost of \$15,000 per man. The Norfolk Public Works Center alone employs 21 workmen to repair wooden waterfront structures, primarily fender piles, whereas other activities of the division employ an estimated additional nineteen men for that purpose.

As in all geographical areas having a wet climate, both exterior and interior surfaces of the buildings at the Headquarters Support Activity, New Orleans, Louisiana, must be frequently painted. The painting requirements of the wooden exteriors of most of them has been lessened by covering them with asbestos shingles though the trim and other exposed wooden surfaces, as well as the few remaining buildings with wooden siding, still require frequent painting. The interiors of the buildings also require frequent painting, though the interior walls and ceilings ultimately become speckled with mildew. The Headquarters Support Activity is one of the smaller Naval Activities, yet, it employs five painters on a full time basis.

The few examples cited above serve to illustrate the magnitude of the sums spent by the Bureau of Yards and Docks for painting, both in absolute terms and relative to amounts spent on other maintenance procedures. It is concluded that Mr. Moe's estimate of \$5,000,000 or more as the annual expenditure for painting at Naval Shore Establishments is indeed conservative and a more realistic figure may be several times \$5,000,000 per annum. Excluding the funds for replacement of major facilities, the cost of painting may exceed all other maintenance costs combined.

Microorganisms play a significant though often overlooked role in the deterioration of coatings in the liquid form during storage as well as in the film formed after application. Bacteria decompose the cellulosic compounds used as thickening agents for water based paints which, in turn, lowers the viscosity of the coatings, thereby making application difficult. In stored paints, bacteria often produce a foul-smelling gas causing containers to bulge and occasionally to burst. Fungi are responsible for the mildewing of painted surfaces, a phenomenon especially common in humid climates or in humid enclosures such as bathrooms and showers. On such

surfaces fungi appear as black, green or brown discolorations commonly identified as ordinary "dirt". Recent studies[20] indicate that many commonly occurring bacteria and fungi are capable of hydrolyzing and oxidixing polymeric vehicles of alkyd resin paints. Subsequent deterioration of polymeric binders at the paint-substrate interface is said to contribute significantly to failure of house paints and is manifest by peeling. Bacteria and fungi also deteriorate plasticizers[21] added to paint and plastics to impart softness, pliability and elasticity. Although other agents may cause deterioration of paint and organic coatings, the role of microorganisms is far greater than was formerly suspected.

Inhibitors have been found that are fairly effective in preventing paint spoilage within the can and also impart to the paint some resistance to mildew. The problem is however still of considerable importance and, in some geographical areas, mildew even disfigures paint films formulated with biological inhibitors.

Considerably less study has been made of the deterioration of polymeric binders of paint by microorganisms. In controlled laboratory experiments,[20] several species of microorganisms commonly found on paint film hydrolytically cleave the ester linkages of alkyd resins and other polyesters used as paint vehicles. In the field however, it is difficult to determine the role of microorganisms in the breakdown of the polymeric binding and the subsequent peeling of paint films. The evaluation of a biocide intended to prevent deterioration of the polymeric binder is also difficult. The problem was considered by Verrall[8] and associates at the Southern Forest Experiment Station. They compared the life of paint films on untreated wood and on wood that had been dip-treated in a water-repellent preservative containing 5 percent pentachlorophenol. The paint film on the treated wood had a greater durability. The results might be interpreted as indicating that the paint-to-wood bond was protected from microbiological attack by the pentachlorophenol, though other interpretations are plausible. Considerably more study is needed of the effect of wood treatment on the life of coatings before the importance of the type of deterioration in question can be properly evaluated.

Current interest in the microbiological breakdown of plasticizers is increasing. Plasticizers such as vegetable oil, glycerol and organic acids are generally composed of relatively simple organic molecules that are more susceptible to biological degradation than the larger, more complex polymeric molecules of the paint or plastic to which they are added. The development of coating resins, such as polyethylene, that do not require plasticizers is presently under study. Polyethylene films containing various plasticizers are readily attacked. The unplasticized polyethylene appears to be sufficiently pliable to produce a satisfactory covering for copper wire.

One potential solution to the problem of bacterial decomposition of plasticizers in paints and coatings would entail the search for a non-biodegradable plasticizer. Considerable information on biodegradability of various types of chemical compounds was obtained during a recent search for biodegradable detergents. Some of this information might prove useful in a search for a non-biodegradable plasticizer for paints.

In summary, the funds spent for painting buildings and other structures at Naval Shore Establishments are great and even minor improvements in paint technology would be of considerable economic advantage to the Bureau of Yards and Docks. There are no evidences to substantiate the view that paint films deteriorate spontaneously by processes that could occur in a microbial-free environment; whereas, there are numerous evidences to substantiate the view that microorganisms play at least a partial role in the deterioration of paint films. Investigations of the possible role played by microorganisms in the deterioration of paint films are, therefore, in a principal problem area of the Bureau of Yards and Docks. The probability of an early return from investment in this area of research is, admittedly, not great; but the possible returns are potentially very large.

Mildew on Asbestos Shingles. The preservation of asbestos siding and shingles does not require painting though they gradually become discolored by rust spots, dirt, and mildew. Under such conditions the siding and shingles become unsightly unless painted, a periodic task and expenditure.

Public Works Personnel at the Third Naval District, faced with this problem, considered the feasibility of cleaning the shingles rather than painting them. Inquiry of the manufacturers for suitable methods to clean asbestos shingles revealed that suitable cleaning methods are unknown.

Public Works Personnel at the Eighth Naval District have similar problems with asbestos shingles. Years ago they established a policy of covering wooden siding with asbestos shingles in lieu of repainting. The policy was based on the estimation that the cost of covering the siding with asbestos shingles would be twice that of repainting but that the asbestos shingles would last more than twice as long as paint. They estimated that the asbestos shingles would require no maintenance for at least ten years.

The asbestos shingles on most of the buildings at the Headquarters Support Activity are approximately twenty years old. A black fungus growth on the shingles causes them to appear unsightly but not as unsightly as

wooden surfaces badly in need of a new coat of paint. Furthermore, the asbestos shingles are not subject to fungus decay and the decision to cover wooden buildings in the Eighth Naval District with asbestos shingles appears to have been prudent.

Maintenance personnel at the Headquarters Support Activity discovered that disfiguring black fungus growth and rust spots on asbestos shingles can be scrubbed off with a hypochlorite solution. Unless the cleaned shingles are then painted, they are within six months again covered with the fungus growth and adhering dirt. Maintenance personnel at the activity report that asbestos shingles are treated with a water repellent sealer at the factory. The sealer gradually deteriorates and the small amount remaining after ten or more years of exposure is removed by scrubbing with the hypochlorite solution.

One possible solution of the problem is the development of a water repellent sealer solution that could be applied to asbestos shingles in place. The solution would perhaps be preferable to paint because solutions of water repellent sealer are usually less expensive and easier to apply than is paint. Such solutions generally penetrate deeply into the material to which they are applied and are not subject to cracking and peeling. Unlike paint, however, water repellent sealers do not cover dirt and thus they should only be applied to asbestos shingles that have previously been cleaned with a bleaching agent.

A second possible solution to the problem is the use of darker colored shingles. Shingles used by the Navy are generally white when new and gradually become gray and finally almost black. Asbestos shingles are available in green, red, and white. Arrangements could perhaps be made with the manufacturers to obtain shingles whose color approaches the color of mildew. This would require an advance study of the shades produced by mildewing fungi of asbestos shingles in various geographical areas.

In summary, asbestos shingles are widely used by the Navy and could be employed much more extensively to a considerable economic and aesthetic advantage. Relatively inexpensive, they do not decay, and other than replacement of broken shingles, require maintenance only in a consequence of unsightly fungus spots and rust stains. Reduction of maintenance on asbestos shingles is worthwhile area of investigation which might be solved with a relatively minor research effort. To the author's best knowledge, the problem has not been investigated by other laboratories.

Bacterial Decomposition of Asphalt. The Bureau of Yards and Docks Activities maintain several thousand miles of asphaltic surfaced streets and roads, 70 million square yards of asphalt covered airplane runways, thousand of miles of asphalt coated pipes and cables, and thousands of asphalt covered roofs. Collectively, the activities undoubtedly spend several million dollars annually for the application and maintenance of asphalt surfaces and coatings.

Deterioration of asphalt is a complex and little understood process (Figures 9 and 10). Because asphalts are indefinite mixtures of hundreds of compounds, no two batches are identical. Secondly, the manner of asphalt deterioration is varied, though, the usual mode is the development of hardness and brittleness and the subsequent loss of binding ability that leads to crumbling.[22]

Prior to World War I, the hardening of asphalt was believed to be caused solely by the loss of light oils through evaporation. Since the war, information indicating that oxidation is the pre-eminent reason for asphalt hardening under conditions of outdoor use has steadily accumulated. Evaporation is of major importance during the preparation of hot mixtures of asphalt and aggregates, but is of minor importance during the service life of most asphalt products.

Heat and moisture tend to accelerate oxidation of asphalt and consequently asphalt pavements and coatings deteriorate very rapidly in geographical areas having a hot and wet climate. Air also accelerates oxidation and hence films of asphalt exposed to air deteriorate more readily than thick films, and asphalt pavements having a high "air void" content are more susceptible to oxidation and deterioration than are well compacted pavements. Most bacteria also require heat, moisture, and air to grow at their optimum rate.

Light, also accelerates oxidation and deterioration of asphalt. N. R. Traxler[22] of the Highway Research Institute, Agricultural and Mechanical College, Texas, reviewing the effects of light on asphalt pavement states. "A very thin layer of the pavement is severely affected by photooxidation and probably is responsible for much of the deterioration of the wearing surface. The exposed films become very hard, lose adhesiveness, and erode away." (Incorporation of aluminum pigment into the outer layer of pavement might retard its deterioration.) "However, the effect of photooxidation is not as deepseated as simple oxidation which permeates the pavement through channelized voids."

Quite frequently, chemical reactions stimulated by light are also initiated by microorganisms or enzymes. A classical illustration of the similarity of the action of light and enzymes on organic compounds is the action of sunlight and enzymes on acetaldehyde and pyruvic

acid.[23,24,25] Either of the two compounds can be converted to a compound called acetylmethylcarbinol by the action of light or by the action of enzymes. "Nascent" acetaldehyde is believed to be the principal intermediate in both the photochemical and analagous enzymatic reactions. The fact that light degrades asphalt suggests that living organisms might also be able to degrade asphalt.

In recent years there has been a growing conviction that bacteria are involved in the deterioration of asphaltic materials. Hundeshagen,[26] 1934, was perhaps the first to report on the degradation of asphalt by microorganisms. Since that time a number of individuals have studied the action of bacteria on asphalt and other bituminous products. J. O. Harris[27] and associates at Kansas State University, R. W. Traxler[28] and associates[29] at the University of Southwestern Louisiana, Burgess,[30] Kulman,[31] and Martin[32] have all confirmed the action of microorganisms on asphalt and asphalt products. Some of the evidence that incriminates bacteria in the breakdown of asphalt are discussed in the following paragraphs.

Many bacteria can grow in media containing bituminous hydrocarbons. In the laboratory, asphalt is rapidly degraded by several species of Pseudomonas, and Bacillus. R. W. Traxler[28] demonstrated that in a week bacteria degraded as much as 25% of the asphalt available in culture flasks, and they required no other source of carbon.

Organisms capable of living on bituminous hydrocarbons are found in great numbers in soil adjacent to asphalt pavements and asphalt coated pipes, whereas only a few such organisms are found in the soil a little further away. Harris[27] and his associates found ten thousand asphalt utilizing bacteria per gram of soil in the soil adjacent coated pipes and fewer than 100 bacteria per gram of soil a few feet away. This suggests that some bacteria may utilize asphalt of coatings and pavements as a source of nutrients.

As previously stated, oxidation is the usual process involved in the deterioration of asphalt. Oxidation is also the process involved when bacteria metabolize bituminous hydrocarbons. This suggests that if bacteria were to metabolize asphalt hydrocarbons, they would cause it to be oxidized and thereby cause it to deteriorate. Likewise the "asphaltic bacteria" demonstrate maximum metabolism at environmental conditions of temperature, moisture and oxygen that prevail during maximum asphalt deterioration.

In Russia, Volkova[33] tested a number of compounds as oxidation retardants for asphalt and he found small amounts of sulfur, tannin, naphthol, sulfanilamide, sulfapyridine, pyrocatechin, and alizarin to be effective. Of considerable interest is the fact that these compounds are all known to be bactericides. That such compounds protect asphalt from oxidative deterioration suggests that the compounds prevent growth of bacteria that metabolize asphalt. (However other explanations are also plausible.)

In summary, there are many reasons to suspect that bacteria are involved in the degradation of asphalt and research in that area might result in substantial savings for the maintenance of asphalt pavements and other asphalt products at Naval Activities. Research is required to determine the importance of microbial oxidation in the overall process of asphalt deterioration, and field studies are needed to evaluate the effectiveness of additives that prevent bacterial oxidation. Because bacteria display specificity in hydrocarbon oxidation, tests for classifying or rating asphalts according to bacterial activities within them are also distinct possibilities. Many physical and chemical tests now performed presumably predict the effective life span of asphalt though, admittedly, such tests are of questionable value. Bacterial tests might be more specific and more suitable for the routine testing of large numbers of field samples.

<u>Bacterial Corrosion of Iron and Steel</u>. Corrosion problems at Naval Shore Establishments vary with the location of the structure. Metal structures that are buried, situated above ground, or located on a waterfront each exhibit unique patterns of corrosion and each requires different maintenance and corrosion prevention measures. Some of the problems formerly existing have been recently eliminated, but several remain unsolved. The question of whether bacteria play a major or a minor role in the corrosion of iron and steel has yet to be answered.

Corrosion of buried utilities at Naval Shore Establishments is rapidly being reduced by cathodic protection and by the use of substitute materials. In 1953, several buried fuel tanks in the Eighth Naval District rapidly corroded even though the exterior of the tanks had been covered with an asphaltic paint prior to installation. In 1953 and 1954, cathodic-protection equipment of the impressed voltage type was installed on all of the buried fuel and water tanks in the district at an installation cost approximately one to ten percent of the cost of the tanks. Measurements made in 1964 indicate that very little corrosion, if any, has occurred since the cathodic-protection equipment was installed.

Buried fuel and water lines in the Eighth Naval District have a similar history and, prior to 1955, frequent replacement or repair of buried pipes was necessary. At the Dallas Naval Station, for example, the monthly cost of repairing buried fuel and water lines was in excess of one thousand dollars. In 1955, cathodic-protection equipment of the impressed voltage type was installed on all buried pipes, and the need for repair since has been negligible.

Since the corrosion of metal structures above ground cannot be arrested by cathodic protection, corrugated steel shops, warehouses, coal bunkers, and similar structures still present maintenance problems. Painting is the sole effective maintenance procedure for such buildings. Primers that prolong the life of overcoated paint film applied to metal structures have been developed, yet paint still fails as is illustrated in Figure 11. In many instances, rusting of the underlying metal appears to precede the peeling of the paint. The importance of bacteria in corrosion under paint films is not well established. Frequently, corrosion of corrugated steel structures also occurs where wood contacts metal, a problem especially severe in geographical areas having a tropical climate.

The major corrosion problems at Naval activities occur on the waterfront. In every Naval District at least one major waterfront structure is failing or has recently failed and been replaced as a consequence of the corrosion of structural iron or steel. The structures involved are typically fifteen to twenty years old.

As yet measures to prevent corrosion of steel waterfront structures have not been as successful as are the measures preventing corrosion of buried tanks and pipes. Cathodic protection does not prevent corrosion of portions of steel structures extending above or suspended above the water line, the region of most severe corrosion, and cathodic protection is not widely used to prevent the corrosion of the submerged portion of steel waterfront structures. Furthermore, the use of protective coatings to prevent the corrosion of waterfront structures has met with but limited success. (All of the visited activities were interested in obtaining new information on efficient protective coatings for the splash zone.) New and better protective coatings and new methods to prevent the corrosion of waterfront structures are sorely needed.

Corrosion of steel bulkheads, underdeck piping, and other waterfront structures, such as the light pole shown in Figure 12, is rapid at most east coast harbors, though exceptions do exist. At Quonset Point, Rhode Island, for example, a steel bulkhead less than twenty-years old is failing; whereas across the bay at Newport, Rhode Island, a steel bulkhead

forty-years old remains in good condition. Even an experimental concrete jacket failed to halt the corrosion at Quonset Point. One explanation for the difference in service life of the bulkheads in the two harbors is the degree of pollution of the water. At Quonset Point, the harbor water is highly polluted; whereas, at Newport, tidal action brings clean water of the deep off-shore channel to the harbor. Another cause for the differences cited is that oil on several occasions had been accidently spilled near the bulkhead in the Newport Harbor, thereby coating the bulkhead with a thin film of oil. (The age-old house-hold method to prevent rusting, periodic spraying with a thin coat of oil, might save the Navy considerable sums.)

A twenty-year old bulkhead or sea wall several miles long at the Naval Air Station, Floyd Bennett Field, New York,[34] is in an advanced stage of deterioration. For several hours before and after low tide, most of the structure is completely dry. A large section, shown in Figure 13, is badly perforated in the mean low tide zone so that it no longer retains the earthen fill. Other sections, such as that shown in Figure 14, still retain the earthen fill, but they are in need of extensive repair.

During World War I, an extensive wood-piling bulkhead was constructed at the U. S. Naval Base, Norfolk, Virginia. During World War II, the base was modernized and concrete decked, sheet steel bulkheads were installed. The sheet steel piling was driven a short distance in front of the old wooden bulkhead (which was not removed) and an earthen fill was placed between. By 1956 it was already apparent that the new bulkhead was rapidly deteriorating. A view of one section of the bulkhead as it appeared in 1956 is shown in Figure 15. By 1959, the steel bulkhead was perforated at many spots (Figure 16) and large sections of the steel whaler had fallen off. In late 1959, during Hurricane Donna, the steel bulkhead collapsed and released the fill between the old and the new bulkheads. Fortunately, the older wooden bulkhead remained intact and prevented more serious damage. The two bulkheads have since been faced with a third bulkhead of concrete and steel. Should that fail also, the old wooden bulkhead, remaining intact a few feet behind, will again serve its intended function.

In recent years, steel H-piles have replaced wooden piles in the piers and wharves at Naval Activities on the Gulf Coast. The piles corrode even though they are heavily covered with a bitumastic coating before being placed in the ground. Corrosion occurs primarily at, or just above, the water line and occasionally at, or just above, the mud line. Various splash zone coatings have been employed to prevent this corrosion; but at the breaks or cracks that eventually develop in the coatings, corrosion occurs more rapidly than if there was no coating. Corrosion that would

have occurred uniformly over the surface of the steel piles is concentrated at sites of breaks and cracks in the coating. Steel piles of the Galveston pier are now being encased in concrete extending several feet below the water line, though it is not at all certain that the concrete caps will prevent further corrosion. Such caps did not prevent corrosion of steel piles at Quonset Point, Rhode Island, nor at the Boston Naval Shipyard. Whether the steel pile of the piers at the various gulf ports will last sufficiently longer than wooden piles to justify their higher cost remains to be seen.

Perhaps the largest of the steel waterfront structures in the Eighth Naval District to succumb to corrosion were two breakwaters at Corpus Christi, Texas. The breakwaters (Figure 17 and 18), constructed of huge steel cylinders, were decked with concrete. They are but fifteen years old and are riddled with holes at the water line. One will be abandoned and attempts will probably be made to repair the other.

In the future the Bureau may assume a primary responsibility for the design, construction, and maintenance of floating bases in mid-ocean and of underwater bases or structures both on the continental shelves and in the deep ocean. In the future, Bureau activities can therefore anticipate corrosion problems in these new environments.

There is considerable evidence indicating that microorganisms are frequently involved when iron corrodes.[35] If this is true, it is certainly a matter of prime importance to the Bureau and thus a brief review of the evidence is in order.

It is well established that the immediate chemical reaction called corrosion is an electrochemical reaction rather than biochemical. Microorganisms, however, release chemicals into the immediate environment of the iron, or remove them from this environment thereby causing changes in the corrosion rate. The discharge of metabolic by-products of bacteria can even cause rapid, severe corrosion to occur in an environment where corrosion would otherwise not occur at a significant rate.

Aerobic corrosion of iron proceeds quite readily in the presence or absence of bacteria. Bacteria, however, can accelerate aerobic corrosion if they have the proper substrate upon which to grow. In an environment of abundant air and water, for example, some bacteria can convert sulfur or a number of sulfur compounds into sulfuric acid of sufficient concentration to rapidly perforate steel pipe (and even concrete pipe). Such bacteria cause considerable damage to crude oil pipe lines. Aerobic bacteria also produce carbon dioxide, numerous organic acids, and countless other compounds. It is well established that

carbon dioxide accelerates aerobic corrosion, but the influence the majority of the other bacterial products cited have on aerobic corrosion is not well known.

Anaerobic corrosion of iron (i.e., in the absence of oxygen), on the other hand, does not proceed at an appreciable rate unless the metabolic wastes, such as hydrogen sulfide, produced by certain anaerobic bacteria[36] are present. Under such circumstances iron corrosion may occur more rapidly in the absence of oxygen than in the presence of oxygen. For example, when conditions are ideal, bacterially induced anaerobic corrosion can destroy a heavy steel casing in a three month period. Such occurrences are frequent in oil wells.

In the thin film of bacteria and slime that readily accumulates on the surface of iron structures in the ocean, the concentration of dissolved gases differs considerably from that in the surrounding water. Both the bacteria in the film and the iron to which it is attached remove oxygen from the water faster than it can diffuse through the film, and consequently, conditions in the film are frequently anaerobic and ideally suited for the growth of hydrogen-sulfide-forming bacteria. Anaerobic corrosion can, therefore, occur even in well-oxygenated areas of the ocean. Iron buoy chains, for example, are frequently covered with heavy black deposits and have the tell-tale odor of hydrogen-sulfide. Deep craters and grooves are found on the chains when the black deposits are removed. However, the adhering film of bacteria and slime can serve to merely lower the concentration of oxygen, not to create anaerobic conditions. In such instances, the bacterial film probably retards corrosion significantly.

The presence of unicellular photosynthetic organisms in the ocean is well established and in sunlight they liberate oxygen, one of the principal agents accelerating corrosion. Where and how extensively diatoms and other photosynthetic organisms accumulate on the surfaces of iron and steel structures immersed in the ocean has received but scant attention. These organisms might well play an important role in the corrosion of metal structures in the splash zone.

In summary, the corrosion of iron is a problem of major economic importance to the Bureau of Yards and Docks. The question at hand is the significance of bacteria or other microorganisms in the corrosion of Naval structures. Unfortunately, a simple yes or no answer cannot be given. Bacterial processes probably do not significantly alter the aerobic corrosion of structures above ground. It is well established however, that anaerobic bacteria are frequently involved in the corrosion of underground utilities, though cathodic protection is usually effective in combating this form of corrosion. Bacterial processes undoubtedly have a marked influence on the corrosion of structures wholly submerged in

the ocean. In most instances the bacteria probably retard corrosion of submerged structures by reducing the concentration of oxygen. However, in frequent instances, bacterial processes promote very severe and rapid corrosion of iron submerged in the ocean. Bacteria are of dubious significance in promoting corrosion in the splash zone, the area of most concern to the Bureau. Sulfur-oxidizing bacteria and photosynthetic algae might accelerate splash zone corrosion in several ways, but even if economical methods were available to stop the growth of microorganisms on steel surfaces, splash zone corrosion would still proceed quite rapidly. It is a distinct likelihood, however, that bacteria promote deterioration of coatings employed to prevent splash zone corrosion and easy-to-apply coatings that are resistant to microbial degradation (and ultraviolet damage) are sorely needed.

Deterioration of Concrete. Since World War II, wooden piers and wharves have gradually been replaced by structures of concrete and steel. This change has not necessarily resulted in savings for the Bureau, for concrete and steel also deteriorate in an ocean environment. A number of instances in which steel waterfront structures failed after a relatively brief period of service were cited in the previous section of this report. Examples of failure of concrete waterfront structures after a relatively brief period of service are cited below.

In May 1959, the District Public Works Office, Fifth Naval District, presented several case histories[37] involving failures of waterfront structures at Portsmouth, Virginia. The following excerpt was taken from this report: "An investigation or precast concrete piles in marine environment was precipitated in October 1958. At that time, annual surface inspection (by boat) of piers at the Norfolk Naval Shipyard, Portsmouth, Virginia, revealed spalling of concrete piles in the vicinity of mean low water (MLW). This condition was unique since the deterioration did not occur entirely within the tidal range, but progressed from the vicinity of MLW downward into the water and out of view. Navy divers were requested to make a preliminary underwater investigation to ascertain the extent of spalling and it was found that this condition existed to the mud line or within 2 feet thereof. While a more complete underwater investigation was being made at the Shipyard, piling at other activities was checked and 2 additional similar cases were discovered."

At the Norfolk Naval Shipyard deteriorated concrete piles were found at five piers (Figure 19) and at the Naval Hospital where the piles "supported a boathouse of brick masonry construction." Deterioration was also found at the Naval Ammunition Depot, where affected concrete piles supported a reinforced concrete ammunition loading wharf. The superstructure of all three installations were described as still "in excellent condition". All of the above structures were constructed during the period, 1944-1948.

Premature deterioration of the concrete piles at the Portsmouth activities has been "ascribed to electrochemical affects which result when reinforcing steel in concrete is cathodic to its environment." The conclusion was based on the National Bureau of Standards Circular. "Electrolysis in Concrete", describing the softening of concrete and the deterioration of the concrete to metal bond when the reinforcing iron is cathodic to the concrete. Normally, steel in concrete piles is not cathodic to its environment unless an external voltage is applied, but in the first two of the instances cited, the steel in the portion below water was cathodic and did not rust (Figure 19). The steel above water was anodic and underwent corrosion (Figure 20).

In an alternate explanation, the premature deterioration of the concrete was attributed to use of the incorrect type of cement (high-early-strength; i.e., high content of tricalcium aluminate) and to industrial pollution of the Elizabeth River. The latter explanation is generally accepted as the more accurate, but it cannot explain the satisfactory performance at the Cooper River Bridge of eleven precast piles of the same type and from the same shipment as those used at the Norfolk Naval Shipyard.

The immediate cause for the deterioration of the pre-cast piles at Portsmouth is cited as a "chemical reaction between the hydrated cement and one or more substances present in the waters of the Elizabeth River". "The chemical reaction between the sulfate in sea water and the hydrated cement is commonly referred to as sulfate attack." The possibility that microbial activity may have initiated or accelerated the attack was apparently not considered though the ability of marine bacteria to produce sulfates is well known and the ability of diatoms to decompose aluminum silicates is well established.

Failure of a concrete waterfront structures also occurred at San Diego, California, where the concrete quay wall at the U. S. Naval Amphibious Base require extensive repair. Because of construction cracks, subsidence has occurred behind the walls and it is estimated that $1,200,000 is needed to alleviate this problem.

Failure of concrete also occur on terrestial structures. Spalling of concrete in the barracks at the U. S. Naval Station, Bermuda became severe but five years after the completion of construction (Figures 21, 22, and 23). It is reported that the above problems resulted from the use of sea water in mixing the concrete and plaster. Similarly, in the Eighth Naval District concrete and steel dormitories at Orange, Texas have been severely damaged in consequence of the corrosion of the metal lath and steel reinforcement. The complete extent of the damage was not ascertained.

The structures described above are certainly not typical of concrete structures of the Naval Shore Establishment and the examples are presented merely to illustrate that use of reinforced concrete in lieu of wood does not terminate problems of deterioration, The majority of the great number of concrete structures at Naval Establishments appear to be in good condition, though many concrete waterfront structures have been but recently installed (since World War II) and more time is required to establish their useful life span.

Effect of Fouling on Waterfront Structures. Problems associated with the attachment of barnacles and other macroscopic organisms to the surfaces of waterfront structures is currently not a major problem at most Bureau of Yards and Docks Activities.

Fouling of fixed waterfront structures often lends an unsightly appearance but it generally does not interfere with their basic function. Fouling may accelerate deterioration of fixed waterfront structures by destroying their protective coatings and hastening corrosion, though maintenance funds are seldom used to remove this fouling.

Problems associated with fouling of floating structures at Bureau of Yards and Docks Activities are however of somewhat greater concern. Pontoons, mooring buoys (Figure 24), floating causeways (Figure 25), barges, and the like must be removed periodically from the water for cleaning and repainting. Fouling organisms may not only d stroy protective coatings but frequently acquire such immense bulk and weight as to interfere with the structures function. More than one hundred mooring buoys are maintained at the Naval Base at Pearl Harbor and approximately one hundred are maintained at Naval activities in San Diego Bay though other Naval establishments generally maintain a lesser number of mooring buoys or none at all. Data on the numbers of other types of floating structures maintained at various Naval Bases were not available but, with the exception of individual pontoons, it is unlikely that such structures are as numerous as mooring buoys.

Problems involving fouling of sea water intakes likewise occur frequently at numerous Naval establishments, as for example at Pearl Harbor, though to some extent the problem has been satisfactorily solved at other activities with the addition of chlorine to the water. The fouling of sea water intakes will be discussed more fully in another section of this report.

The Bureau of Yards and Docks annual expenditures for combatting fouling presently are not multi-million dollar sums, but the amounts expended are not insignificant and certainly add up to many thousands of dollars each year.

There are several cogent reasons for suspecting that, in the future, fouling problems will increase in importance at Bureau of Yards and Docks Activities. Because of the presence of biocidal pollutants in the water, fouling is light in many harbors. The "clean-up" of American rivers and estuaries, now being initiated, will serve to increase the growth of marine organisms in these waters and thus to promote or accelerate fouling problems at many harbors. Secondly, improved organic coatings are being developed and, therefore, increased use of protective coatings on fixed waterfront structures can be anticipated. The efficiency of such coatings on fixed waterfront structures would be impaired by the presence of fouling organisms. Thirdly, inflatable pontoons and inflatable causeways,[38] currently being tested, are expected to go into field use within a year. The rubber-like materials used in the construction of these structures are susceptible to damage from marine fouling (Figures 25 and 26). Perhaps the most important contemporary consideration of fouling concerns the facilities floating in mid-ocean (Figure 27), suspended on the continental shelves, and even submerged in the deep ocean (Figure 28). Fouling will not only accelerate the deterioration of such structures but might, in some instances, completely engulf the structures amidst tons of living debris unless effective measures are found to prevent such attachment.

Many laboratories are evaluating anti-fouling paints both in the laboratory and in the ocean. In view of the diminishing returns now accruing from such investigations and in view of the excellent program in this area now underway at Bureau of Ships Laboratories, such evaluation studies are not advised for the U. S. Naval Civil Engineering Laboratory.

To date, the important initial stage of fouling, the formation of a "primary film"[39] of dissolved organic material, bacteria, diatoms, algae and other marine microorganisms, has received but scant attention. The formation of the primary film is not only the first step in the process of fouling by microorganisms, but it is the first step in the process of bacterial corrosion of metals and in the bacterial decomposition of protective coatings. Attachment of microorganisms is also the primary step in terrestial processes of biodeterioration.

Recently performed studies have uncovered facts that are altering long held concepts of the sequence of events in the fouling process. ZoBell, at Scripps Institute of Oceanography, has demonstrated that adsorption of dissolved organic matter to surfaces exposed in sea water precedes the attachment of the bacteria. The bacteria feed on the adsorbed organic material and may be attracted by it. A brief unpublished study[40] at a neighboring industrial laboratory revealed that pure cultures of marine bacteria do not readily adhere to surfaces exposed in sea water. When algae are also growing in the sea water, however, the bacteria become attached to the surfaces.

The composition of the cementing substances produced by algae, and how it adheres to surfaces, is not known. Whether it functions as an attractant as well as an adhesive is also not known. Answers to these questions would likely provide clues for methods to prevent the attachment of macro and microorganisms to the surfaces of structures submerged in the ocean. A similar attack on the mechanism of adhesion led to the recent development of vastly improved adhesives. To the best of the authors knowledge other Navy Laboratories are not engaged in studies to elucidate and prevent the formation of the "primary film". Because this area of investigation is so basic to the problem, and because it is relatively unexplored, the area is highly recommended for studies at the U. S. Naval Civil Engineering Laboratory

Relation of Environment to Deterioration of Materials. Greathouse and Wessel[41] in their treatise, "Deterioration of Materials," state, "Every material has a particular set or range of conditions under which it exhibits greatest ability to maintain its most desirable properties. Butter under refrigeration remains useful a long time; that exposed to the conditions of the Sahara Desert soon is spoiled. An untreated fence post under desert conditions remains free of rot, but the same post in the soil of the Panamanian jungle soon becomes part of the soil through the rotting action of microorganisms thriving by virtue of favorable climate. For one interested in preventing deterioration, therefore the fundamental approach is through a study of climates, coupled with a study of behavior of materials under these climates, and finally through the use of resistant materials or alteration of susceptible materials to make them resistant to the climate to which they will be exposed."

Climate is but one of many environmental parameters influencing the deterioration of structural materials. The endurance of a given structural material buried in soil differs markedly from the endurance of the same material embedded in concrete, immersed in the ocean, or suspended in air. The endurance of a given structural material immersed in the ocean at San Diego may differ markedly from its endurance in the harbor at Port Hueneme and may even vary tremendously at different locations within the same harbor. The reasons for these varying durabilities are found in the physical, chemical, and biological variations of the environments to which the material is exposed.

Many experiences at Naval Activities vividly show the different behavior of a structural material in various harbor environments. One excellent example is the previously cited comparison of the steel bulkheads at Quonset Point and Newport, Rhode Island. The bulkhead, located in the polluted water at Quonset Point is less than twenty-years old and is failing,

whereas across the bay at Newport, a forty-year old bulkhead remains in good condition. The experience with high-early strength concrete piles at the Norfolk Naval Shipyard and at the Cooper River Bridge is another example. Eleven of the 700 piles cast in 1946 for the Norfolk Naval Shipyard were used at the Cooper River Bridge and are still in excellent condition. The remaining 689 piles were placed at the shipyard and all have since failed. Concrete piers at the Portsmouth activities afford yet another example of the variable behavior of identical materials in different harbor environments. The steel reinforcing bars in the concrete piles at the Norfolk Naval Shipyard and the Naval Hospital not only did not rust but in many instances were bright and shiny even though the concrete had crumbled away; whereas at the Naval Ammunition Depot the steel reinforcing bars crumbled when attempts were made to remove the bars from the deteriorated concrete remnants. Protective coatings also vary in their behavior in different harbor environments. For example, an epoxy tar system placed over an inorganic silicate held up well at Port Hueneme but rapidly deteriorated at San Diego.

Records of the behavior of wood at various harbors are replete with reports of apparently anomalous behavior. At Norfolk, greenheart piles appear to outlast all others, creosote-treated or otherwise. In contrast, greenheart piles at Earle, New Jersey (see Figure 5) deteriorate from a type of fungus decay called "shell rot". Other marked differences in the behavior of wood in various harbors are experienced with the use of creosote-treated timbers. At many East Coast harbors, piers constructed of creosote-treated timbers have endured for many decades; whereas at Port Hueneme the useful life of creosote-treated marine timbers is fifteen to twenty years and it is said that their useful life period at Pearl Harbor and Panama is in the neighborhood of five to ten years.

The effectiveness of chemical agents as marine borer deterrents also varies for different boring organisms. Creosote, for example, is very effective against Martesia and Teredo but is only moderatively effective against Limnoria. Organo-tin compounds are likewise more effective in preventing Martesia and Teredine borer attack than in preventing Limnoria attack. Copper compounds, on the other hand, are more effective in preventing Limnoria attack than in preventing Martesia and Teredine borer attack.

A competent civil engineer would not even entertain placing a structure on a site whose bearing properties had not first been carefully studied and measured, though he may not hesitate to erect multi-million dollar waterfront structures with practically no knowledge of the environment in which the structure is to be placed or of the endurance of structural materials placed in that environment.

Before the Navy's huge expenditures for the construction and maintenace of waterfront structures can be significantly reduced far greater knowledge concerning harbor environments and the behavior of various materials in those environments must be accumulated. Exposure tests of many types of materials should be conducted at several depths and location within all Navy harbors. Surveys of the living organisms inhabiting those environments and surveys of the distribution of sewage and industrial was in Navy harbors are required. The undertaking is too large for a single institution to complete but the U. S. Naval Civil Engineering Laboratory could develop many of the methods and instruments required; and the Laboratory could clarify and perhaps coordinate the field studies that must be made at the individual activities. (Further discussions of methods for surveying the environment of marine structures will be presented in future sections of this report.)

Summary of the Biological Deterioration of Materials. From a financial consideration, the deterioration of engineering materials is, by far, the most significant problem facing Bureau of Yards and Docks activities. Deterioration of wood, asbestos siding, paint, asphalt, steel, and concrete are all annual multi-million dollar problems. Engineering materials deteriorate in consequence of complex, little understood, and intertwined biological, physical, and chemical processes. Though the relative importance of the biological, chemical, and physical processes are difficult to evaluate individually because of their interdependence, the importance of the role played by biological processes in the deterioration of structural materials is amply confirmed.

The methods now used at Bureau of Yards and Docks Activities for preventing the deterioration of engineering materials were developed in prior research of many laboratories. Savings due to current methods of preventing deterioration are almost too great to comprehend; yet, new and even better methods are sorely needed. Only if numerous investigations are undertaken at many laboratories, will new methods to prevent the deterioration of engineering materials be developed.

SANITARY ENGINEERING

The Nation is engaged in its greatest effort in history to clean-up its atmosphere, its rivers, and its harbors. In his recent State of the Union Message, President Johnson called upon all Americans to unite behind this effort. He proposed that "We increase the beauty of America and end the poisoning of our rivers and the air we breathe." He declared,

We will seek legal power to prevent pollution of our air and water before it happens. We will step up our efforts to control harmful wastes, giving first priority to the clean-up of our most contaminated rivers. We will increase research to learn more about control of pollution." Hard pressed to meet the demands this effort imposes on them, Naval Sanitary Engineers require all of the assistance that the U. S. Naval Civil Engineering Laboratory is capable of giving.

<u>Harbor Pollution</u>. It has generally been believed that the quantities of water available for the dilution of wastes is more than adequate at most coastal harbors. On the other hand, dilution in estuaries and bays is generally far less than satisfactory. A serious threat to the assimilative capacities of rivers and estuaries now occurs throughout the nation; and the marine and river waters of the harbors in which most of the United States Naval Establishment is located are heavily polluted with sewage and industrial wastes.

The consequences of the pollution of rivers, bays, and estuaries are many and varied. Pollution has been indicated in the spread of hepatitis in New England and New York. Sewage contamination of lucrative clam beds in New England has resulted in their condemnation by Public Health Departments.[42] Dredging in the polluted harbor at New London, Connecticut, has released gases of sufficient reactivity to damage paint on neighboring buildings and the property owners demand that the Navy make restitution for the resulting damage. A similar, though less severe incident recently occurred in Long Beach, California. Water pollution is also a major factor in extremely rapid deterioration of sheet steel bulkheads and concrete piers on the eastern seaboard. In California, massive kelp beds have been destroyed by discharge of wastes from the San Diego Harbor, a distance of ten miles from the kelp beds.[43] Water pollution has also caused considerable curtailment in the use of harbor and adjacent beach areas for recreational purposes. Both fishing and swimming are, for example, forbidden in most of the New York waterfront area. It is apparent that remedies must be found to prevent such dire consequences.

The establishment of responsibility for water pollution is a sensitive problem and most commonly the blame is assigned to others. The Navy contributes significantly to this problem by the discharge of raw sewage from ships and even from shore-based establishments. The Navy has always contended, however, that its contribution to the total pollution of rivers and harbors is negligible, a practice followed by most of the organizations that discharge wastes into marine and river waters. Before harbor pollution is eliminated, it is necessary for all involved to concentrate on "what can be done" rather than "who is to blame".

The Hampton Roads Sanitation District Commission treats all, save minute quantities, of raw sewage from land areas under its jurisdiction and thus has reduced pollution from land areas by 95 percent. The gains so achieved through better treatment of wastes generated on land are, however, somewhat negated by the discharge of wastes from nearby ships. The unusually large complement of men on Navy capital ships in the Hampton Roads area produce quantities of sewage equivalent to that of a small town. When the ships are accompanied by an escort, the amount of sewage produced is equivalent to that from a small city. In January 1961, the cognizant Naval Sanitary Engineer proposed that the Bureau of Yards and Docks sponsor an investigation into methods of handling sewage wastes from Naval vessels in the Hampton Roads area. Action on the proposal was deferred.

In 1963, the U. S. Public Health Service, Region 7, Dallas, Texas, recommended that the Eighth Naval District provide facilities to collect and treat sanitary wastes from personnel of ships berthed at Navy piers in New Orleans. At the same time, the District was preparing plans for the reconstruction of 800 feet of its wharf at New Orleans. The District Naval Sanitary Engineer was requested to review the plans and make the necessary additions in compliance with recommendations of the Public Health Service. At the suggestion of the Sanitary Engineer, the District Public Works Officer submitted a letter to the Chief, Bureau of Yards and Docks, requesting guide lines for designing the required facilities. The Chief, Bureau of Yards and Docks, replied that the Eighth Naval District should comply with the recommendations of the U. S. Public Health Service and should provide a system for collecting and treating sewage from all Naval ships designed to discharge their sanitary wastes to shore.

The requested systems cannot be constructed at Navy piers and wharves at the present time, as there are but few, if any, ships designed to collect and discharge sanitary wastes to shore. It seems appropriate, however, for the U. S. Naval Civil Engineering Laboratory to initiate studies of various possible methods for receiving sanitary wastes from ships tied up at Navy owned berthing facilities. Systems in which most of the required pumps and apparatus for sewage handling were provided by shore establishments would free the ships of the need to transport additional equipment for that task.

A study of the discharge of raw sewage from ships recently began at the Fluid Processes Branch, U. S. Navy Marine Engineering Laboratory, Annapolis, Maryland, and overall responsibility for the problem may now be assigned to that group. The problem is, however, immense and the capabilities of many engineering groups will no doubt be involved before the discharge of raw sewage from berthed ships into adjacent waters has been eliminated.

Monitoring Bays and Estuaries for Sewage Gases. Field instruments to measure concentrations of various pollutants at various depths in water would be very useful to sanitary engineers. Mr. John Putnicki of the U. S. Public Health Service, Dallas, Texas, believed that harbor pollution studies are seriously handicapped by the lack of suitable instruments for measuring distribution of pollutants. Mr. Putnicki is apparently of the opinion that the present method of bringing samples of water into the laboratory for chemical analysis and bacteriological examination is not satisfactory.

Methods of monitoring river and harbor waters for the presence of specific pathogenic organisms are extremely difficult, unless the organisms are present in large numbers. Coliform bacteria, indicative of human pollution, can, on the other hand, be readily isolated from water that is contaminated by mere traces of sewage. As bacteria of the coliform group form a substantial portion of the gross bulk of human feces, they occur in huge numbers in rivers or harbors into which sewage is discharged. In the presence of fecal matter, pathogens are likely to occur, as fecal matter is one of the principal agents for the transmission of pathogens causing typhoid, cholera, polio, and dysentary. Thus, counts of coliform bacteria in water are standard measures of the presence and degree of sewage pollution and hence they are indices of health hazards. Unfortunately, coliform bacteria cannot be counted with field instruments, and forty-eight hour laboratory tests are required.

In addition to coliform bacteria, the feces of man and many warm-blooded animals contain a number of characteristics organic compounds not normally found in unpolluted water. One such compound, skatole, is a principal agent imparting odor to feces. Decomposing fecal matter also produces ammonia, methane, and hydrogen sulfide and though the latter compounds do not characterize fecal matter as uniquely as does skatole, they occur in far greater concentration in polluted water than in unpolluted water. It is suggested that measurements of the concentration of the above mentioned compounds could be employed as indices of the degree of water pollution in lieu of coliform determinations.

Field instruments for measuring the concentration of compounds of fecal origin in water could conceivably be developed. Many compounds characteristic of feces are either gases or volatile organic compounds that can be readily separated from water. With an instrument consisting of a gas analyzer and a counter-current gas exchanger, it may be possible to measure concentrations of dissolved gases in a stream of water or mud pumped from various depths and locations. The distribution of oxygen, skatole, hydrogen sulfide, ammonia, methane, etc., in and around harbors and sewage outfalls might thereby be ascertained. Of course, instruments for measuring concentrations of specific non-volatile compounds in a stream of water might also be developed.

Knowledge of the distribution of compounds of fecal origin in Navy harbors and adjacent waters would serve many useful purposes. This information might, for example, serve to indicate unsafe areas for dredging or the existence of potential health hazards. Sanitary engineers could possibly determine dilution rates below sewage outfalls and thereby establish safe loads for outfalls. The information would be useful to Bureau of Yards and Docks Activities involved in possible disputes concerning the relative magnitude of their contribution to the contamination of neighboring clam beds or recreational areas. The same information would be useful to materials engineers selecting materials for waterfront structures or to applied scientists studying the influence of pollution and harbor environment on engineering materials. The collection of data on the distribution of sewage components, in and around Naval harbors, is a most worthwhile endeavor for the U. S. Naval Civil Engineering Laboratory and would involve the development of appropriate instrumentation.

Stabilization Ponds. Stabilization ponds are bodies of water into which sewage is discharged and retained until rendered stable and unobjectionable by natural biochemical process. Stabilization ponds are economical and almost trouble-free when properly established and maintained. A comparison of the merits of stablization ponds and conventional sewage treatment plants was recently presented in the Navy Civil Engineer by Edward F. C. Lau,[44] Sanitary Engineer, DIRPACDOCKS, Pearl Harbor, Hawaii. Mr. Lau demonstrated that initial construction costs for conventional sewage treatment plants serving 900 to 1000 persons was 370 percent greater than the construction costs of a stabilization pond, and maintenance costs of the conventional sewage treatment plant are 775 percent greater.

Because of the present effort to reduce the volume of sewage discharged into rivers and harbors, both military and non-military institutions are constructing many new sewage treatment plants, the cost of which increase annually. As a consequence of rising costs of such plants, more of the less expensive stabilization ponds are now being constructed. In 1957 municipal stabilization ponds in the U. S. numbered 631, and Mr. Lau stated that the number has probably tripled since that date.

Stablization ponds, however, have certain inadequacies. They are, for example, operable only in geographical areas having a mild climate since microbiological processes of sewage decomposition do not occur in freezing weather. The area required by a successful pond is another factor limiting their use. The wastes from 200 persons require about one acre of pond.

Mr. Lau believes that the per acre capacity of stabilization ponds can be increased in several ways. Such possibilities involve the union of conventional units, as septic tanks and aeration units, with the stabilization pond. Research and field trials of the combination units might lead to developments that could significantly reduce the costs of sewage treatment at Naval activities.

Polar Sanitation. The design and operation of polar camps has been an important part of the Bureau of Yards and Docks responsibilities for a number of years. Satisfactory facilities for disposal of human wastes, trash, and garbage and satisfactory water supply systems are continuous design and operational problems for polar camps. Sanitation is complicated by the difficulty of obtaining adequate supplies of fresh water in the liquid state for dilution purposes. A further complication is the ability of intestinal pathogans to survive for long periods in the cold polar seas or in the ice and snow.[45] Human wastes, forty-seven years old, at the South Pole, were found to still contain viable intestinal bacteria.[46]

The U. S. Naval Civil Engineering Laboratory's studies on polar sanitation[45,47] has led to preeminence in this field. Results and conclusions from these studies and the plans for future investigations have been adequately described in numerous Technical Reports and Notes from this Laboratory. It is anticipated that such studies can continue to be fruitful for many years to come.

Trash and Garbage Disposal. Collection and disposal of garbage is a continuing problem at Naval Activities. Despite constant efforts to maintain tidy trash cans and garbage dumps, these areas frequently become untidy and ultimately feeding grounds for unwanted birds, rodents, and insects.

In the Boston area, Naval activities attempt to separate garbage and burnable trash. The garbage is removed by a hog farmer though he refuses to accept the garbage when mixed with trash, a frequent occurrence which delays garbage removal. At Norfolk, the garbage dump is a major attraction for birds. A waste-heat incinerator, which will eliminate the need for the dump, shorten the haul required for garbage, and make use of the garbage as a source of heat, is now under construction.

The use of disposable containers would eliminate frequent transfers and spillage of trash and garbage and the re-use of dirty garbage cans and dirty waste receptacles. Disposable containers pretreated with germicides and insecticides would be especially desirable. An evaluation of appropriate containers now available is a worthwhile project for the U. S. Naval Civil Engineering Laboratory to undertake and if such containers are non-existent, the Laboratory might design one.

Contaminants in Rain Water Used for Drinking. Rain water is employed for drinking and other domestic purposes at numerous Naval Stations at isolated coral islands in both the Atlantic and Pacific Oceans. Rain water is, no doubt, also employed at a number of mainland bases where there is a lack of potable well or surface water. Rain water collected from or stored in asphalt-covered basins is generally contaminated by numerous compounds leached from the asphalt. Such compounds frequently impart undesirable odor, color, and taste to the water; though their toxicity to man is uncertain.

Guzman[48] made a careful study of the system for collecting rain water at one of the Bahamas. The potable water on the island had an amber color and a distinctive odor whose origin was the asphalt surface of the catchment basins. Though unable to identify the compounds with certainty, he demonstrated that they could be removed with carbon black.

The U. S. Naval Civil Engineering Laboratory occasionally receives inquiries from field activities concerning asphaltic contaminants in rain water. Though there have been no reported illnesses from drinking asphalt contaminated rain water, the substances might cause adverse phsiological effects in the body and may be carcinogenic over a long period of intake. The U. S. Naval Civil Engineering Laboratory could establish the identify of the compounds so that medical officers would have the information required for their evaluation as potential health hazards.

The Use of Sea Water for Sanitary Facilities and Other Utilities. Sea water is employed for sanitary facilities at a number of Naval Establishments on small coral islands and at other localities where fresh water is at a premium and its use for sanitary facilities at polar camps is now under consideration. Sea water is frequently employed in fire fighting and cooling devices even in areas where fresh water is abundant. However, the use of sea water for fire fighting appears to be diminishing and several Naval activities using sea water for that purpose are converting back to fresh water.

Unless preventative measures are employed, sea water systems invariably and rapidly become clogged by the growth of marine fouling organisms. The problem is generally most acute in the intake lines. Turner, Reynolds, and Redfields[49] at the Woods Hole Oceanographic Institution have investigated various methods of preventing fouling of sea water conduits. They found that chlorination of the sea water with residual of 0.25 parts per million gives complete control of fouling in sea water circulating systems. To obtain a residual of 0.25 parts per million, however, sufficient chlorine must be added to overcome the "chlorine demands" of the organic matter in the sea water. Where the chlorine demand is much greater than 3 parts per million, pentachlorphenol is a more economical preventive agent than chlorine. Where very large volumes of sea water are used, the cost of continuous treatment with chlorine has proven to be greater than the expensive of periodic cleaning of the conduits. Many users of large volumes of sea water employ a reverse flow[50] system where hot effluent water is periodically fed through the intake tunnel to eliminate fouling organisms, a method used very successfully at a number of non-military power plants in California.

An "electric field barrier" installed in 1959 is employed to prevent fouling of a large sea water intake for the power plant at the Pearl Harbor Naval Shipyard. According to information received from Pearl Harbor,

the fouling rate has been reduced 50 percent though fouling organisms still accumulate in the system at about the rate of 70 tons in four years. Castle,[51] at the Woods Hole Oceanographic Institution, demonstrated that control of fouling by electricity can only be accomplished by direct current densities of the order of 1 to 5 thousand milliamperes per square foot, an amount considerably greater than the current densities used at the Pearl Harbor installation.

In operating the saline conversion plant, San Diego (now at Guantanamo Bay), difficulty in preventing kelp from clogging the intake screen was encountered. A similar problem has been encountered at a non-military power station in Ventura County, California. The Boston Naval Shipyard has solved this problem by installing an ingeniously devised self-cleaning screen. An unusually satisfactory system for filtering and chlorinating sea water is in operation at the Boston Naval Shipyard and a report describing the operation and design of their filtering and chlorinating systems would perhaps prove useful to other activities.

An outstanding system for successfully supplying large volumes of sea water is in operation at the New York City Aquarium where large quantities of clean, well aerated sea water are supplied to porpoise and whale pools. The Aquarium obtained its sea water directly from the ocean for many years and experienced considerable difficulty in keeping the lines free of fouling organisms. (Chlorine could not be employed as it would have been harmful to the aquarium animals.) Sea water wells near the shore of the ocean are now employed and they are considered superior in almost every respect and fouling is completely eliminated.

Plastic pipe or plastic-lined iron pipe is employed throughout the sea water system at this aquarium. Though the water comes from a depth of 200 feet, natural flow brings it close to the surface and the pumping problem is not complicated. As the water comes from the ground, it is highly carbonated, contains much dissolved iron and no oxygen. Air is not allowed to contact the water until it is above ground where it is immediately aerated, a process causing rise in pH and the precipitation of iron oxide or hydrooxide. The sea water that remains is essentially iron free and does not leave rusty deposits in lines and reservoirs.

Water obtained from deep wells is generally cool and usually is of uniform temperature throughout the year. Accordingly, such water is ideally suited for cooling. As the use of sea water by Bureau of Yards and Docks Activities is mainly for cooling, it might be advisable to consider sea water wells.

In summary, prevention of fouling in sea water conduits is a problem that frequently occurs at Naval establishments. A number of fairly effective preventative methods are known, therefore, it would appear that research effort could better be expended in other areas. If handbooks or other concise technical documents describing the design and operation of anti-fouling systems for sea water conduits are not already available, preparation of such documents might be a worthwhile undertaking for the Laboratory.

Summary of Sanitary Engineering. One of the major engineering undertakings of the century is now beginning. The President, both Houses of Congress, and the Public, are all pressing for the immediate elimination of the gross pollution of our atmosphere, our rivers, and our harbors. The Navy has a basic responsibility and will be one of the principal beneficiaries of this undertaking. The U. S. Naval Civil Engineering Laboratory has an opportunity to become a part of this great undertaking by channeling a larger portion of its many engineering and scientific skills to sanitary engineering studies.

APPLIED BIOLOGY AND PEST CONTROL

Each District Public Works Officer has a Special Assistant for Applied Biology. The Special Assistants are all highly qualified university-trained individuals, well grounded in entomology and methods of pest control. They keep in contact with all of the field activities, aid in the selection of qualified pest control operators throughout their district, and keep the operators informed of latest methods, encouraging them to increase their competence. The Special Assistants for Applied Biology are individuals who remain up-to-date on pest control problems and methods through constant contact with universities and field stations. They are capable of conducting field research or of arranging for necessary study to be made at neighboring universities or pest control centers. As a consequence most animal and insect pests are at most Naval establishments under satisfactory control and the control is maintained with moderate expense.

The pest control operators are having difficulty controlling a few pests, however, for example an increasing problem of rat elimination. The problem was cited at several of the activities visited and it is reported that the problem is even more acute in tropical areas, particularly in Southeast Asia. The situation may soon improve, however, for several new rodenticides will soon be available. The rodenticides are more effective than those currently used and are harmless to other animals. The methods now utilized to control bird pests and snakes are also inadequate.

Bird Pests. At all of the Naval Districts visited, the Special Assistants for Applied Biology maintain that birds are one of their most annoying pests and one of their most difficult to cope with. The problem is especially acute in southeastern New England in the First Naval District where both gulls and pigeons have undergone a "population explosion".[52] On occasions the problem is also severe in parts of Southern California in the Eleventh Naval District where several off-shore islands provide breeding grounds for great numbers of gulls and other birds. The Navy's Gooney-Bird problem at Midway in the Fourteenth Naval District is perhaps the most heralded bird problem of all.[53] Here, airfield runways were placed on the Gooney-Birds' natural breeding grounds and all attempts to persuade the birds to leave have been futile.

Birds are a constant threat to the safety of jet aircraft. Tragic recognition of that threat was brought to the nation's attention with the crash of the Electra Jet at Boston in October, 1960, which resulted from a collision of the aircraft with a flock of migrating birds. All aboard perished. In 1962, a Viscount commercial airliner crashed at Ellicot City, Maryland, when two whistling swans struck the aircraft's horizontal stabilizer. Seventeen lives were lost. In another incident, an F-101 Fighter crashed when a flock of starlings were ingested into her engines. The plane was a total loss but the pilot escaped. Overall, 430 bird-plane strikes were reported at major U. S. airports from 1961 to 1963. It was estimated that 1,615 unreported strikes also occurred during the same period. Although, to the authors' knowledge, no major accidents involving naval aircraft have resulted from collisions with birds, numerous near accidents have occurred and naval planes are frequently damaged in such collisions (Figures 29 and 30).

Birds frequently become so numerous and bold that they frighten workers. An instance was reported at the Boston Naval Shipyard where large flocks of birds attempting to nest swopped down on men who were repairing a roof and it was necessary to postpone the repair work until after the nesting period.

Bird droppings on exposed surfaces leave them unsightly and cause numerous other problems at Naval activities. The surfaces of decks, metal ladders, cranes, and other waterfront structures covered by bird droppings become very slippery when wet. For that reason, work at the Boston Naval Shipyard is frequently halted during rainy weather. At San Diego, heavy deposits of guano (bird droppings) rapidly accumulate on the exposed surfaces of the many mooring buoys in use at that harbor, and frequently, the buoys must be hoisted from the water so that the guano and fouling organisms may

be removed. Birds in large numbers also enter large open buildings, such as warehouses, hangars, and repair facilities, and contaminate stored equipment and supplies with their droppings. The possible influence of bird droppings on the deterioration of wood is another problem of some magnitude. Deck lumber on wharves and piers is especially exposed to bird droppings and its deterioration is of considerable economic importance. The pest control operator at the Headquarters Support Activity, New Orleans, has noted that wood contaminated by bird droppings frequently decays more rapidly than uncontaminated wood. The observation is understandable as it is well known that growth of wood-decaying fungi is accelerated by the addition of protein or nitrogen-containing salts to the wood on which the fungi are growing. Finally, birds and their droppings are the known vector for diseases communicable to man.

Control procedures now in use at Naval activities consist primarily in the use of bird traps, in the spreading of poisonous bait, and in spraying nests with egg-destroying chemicals. The effectiveness of such control procedures, however, is but temporary. A review of the records at Midway reveal that the bird problem has been alleviated but little, if at all, by many mass clearing and killing programs.

Other procedures to alleviate the bird problem have also met with but limited success. Carbide exploders are effective in frightening waterfowl from the vicinity of airports but have not been very effective against other species. Broadcast bird-distress calls are effective for a few weeks against gulls; but the gulls soon learn that the distress calls are not real, and in time they may even congregate about the "strange" devices that make noises like birds. Removal of food sources has been the only control procedure of lasting effectiveness. Elimination of garbage scows and removal of garbage dumps and sports fishing piers from the vicinity of Naval Activities would be especially helpful in alleviating the gull problem. Education of the public to the realization that feeding pigeons introduces many problems, would help to alleviate the pigeon problem in congested areas such as Boston and New York.

A review of the abstracts of the scientific literature indicates that bird control methods are not being widely investigated. However, universities and government laboratories are conducting research in that area. For a number of years the Bureau of Yards and Docks has sponsored a study of the albatross problem (Gooney Birds) at the University

of Hawaii; and since the crash of the Electra Jet at Boston in 1960, the Federal Aviation Agency has sponsored numerous investigations at Bureau of Sports Fisheries and Wildlife Laboratories. The Office of Naval Research also sponsors minor research tasks on the Albatross problem at the University of Hawaii and at Southern Illinois University; and various agricultural experiment stations throughout the country have for years conducted research on methods to prevent birds from feeding on seed crops. Unless it were to embark on an extensive program of research on bird control methods, it is unlikely that the U. S. Naval Civil Engineering Laboratory could contribute significantly to the effort. A number of engineering aspects of the problem, however, not being investigated elsewhere, might be profitably investigated at the Laboratory.

It appears that very little is known concerning the effect of bird droppings on materials and coatings. An investigation of damage to materials by bird droppings should yield information of considerable value to Bureau of Yards and Docks Activities. Suitable choices of materials and coatings could then be made for those geographical areas experiencing problems with bird droppings. Port Hueneme is an ideal location for conducting such a study as it is close to Anacapa Island, one of the large nesting grounds for gulls and other aquatic birds. An evaluation of bird-repelling chemicals to prevent birds from roosting on selected surfaces, such as mooring buoys and roof tops, might also be a worthwhile undertaking for the Laboratory to sponsor. However, such repellents could probably be evaluated in the field by the Special Assistants for Applied Biology more efficiently than they could be evaluated at the Laboratory.

Poisonous Snakes. Poisonous snakes present control problems at some Naval activities in Southern and Southwestern sections of the United States. At several Naval activities in Texas, Oklahoma, and California, the rattlesnake population is quite large and constitutes a hazard to men working as for example, at the 46,000 acre Naval Ammunitions Depot at McAlester, Oklahoma and at the U. S. Auxilliary Air Station, Chase Field, Beeville, Texas.

The U. S. Fish and Wildlife Service of the U. S. Department of Interior issued an eight page leaflet[54] on the Control of Snakes in 1953. The leaflet has been reprinted several times since and is still perhaps the most informative source of information available on the topic of snake control in the United States. The pamphlet emphasizes that snake control has been studied very little and that the Fish and Wildlife Service does not do research on the

subject. The pamphlet points out that the need for snake control is usually greatly exaggerated; but that when necessary, snake control (in the United States) can usually be achieved by relatively simple procedures. The procedures are described in the pamphlet.

News magazines frequently describe the many poisonous snakes in Southeast Asia where Seabee units are stationed. Direct information on poisonous snakes in Southeast Asia is not readily available but a pamphlet[55] describing the snakes in Thailand was obtained. "Thailand, being a tropical country, abounds with snakes of great varieties, poisonous as well as harmless. Each year a large number of casualties are caused by venomous snake bites. Therefore, the Thai Red Cross Society has established a snake farm for collecting venom which is used to produce anti venom." "Poisonous snakes found in Thailand are Cobra, King Cobra, Banded Krait, Russel's Viper, a few species of Pit Vipers, and some species of Sea Snakes."

By nature, snakes are not aggressive and apparently most snakes are far more afraid of man than man is of snakes. They do strike if they are stepped on, however, and in Southeast Asia snake-bite casualties are very numerous among the civilians who seldom wear shoes. Snake-bites are rare, however, among the well shod U. S. military personnel. Seabees in Southeast Asia have been bitten by snakes, but no deaths have been reported though among other military personnel in Southeast Asia, deaths from snakebite have occurred.

Though few casualties result from snake bites, military and non-military personnel alike frequently fear poisonous snakes. The presence of numerous snake traps and the possession of snake repellents would, undoubtedly, have a favorable psychological effect on personnel stationed in snake infested areas. Different types of makeshift snake traps are employed by Seabee units in Southeast Asia and at some Naval activities in the United States. The development of improved snake traps for use in Southeast Asia might be a worthwhile undertaking for the Laboratory.

Preventive Medical Unit Number 5 at San Diego is studying the snake problem in Southeast Asia and supplies educational material to the Training Officer, Seabee Technical Assistance Team, USN, CBBU, Port Hueneme. A preliminary study is required to ascertain if the Laboratory could be of assistance to the Preventive Medical Units.

Summary on Pest Control. Pest control research is, in general, very costly and highly specialized. Numerous specialized laboratories

and field stations investigating pest control exist throughout the country and such laboratories are better qualified to undertake pest control research than is the U. S. Naval Civil Engineering Laboratory. A few specialized areas of investigation associated with animal pests could, however, be profitably pursued at this Laboratory. For example, it is worthwhile to study the influence of bird droppings on engineering materials and undertake development of pest repelling coatings or effective traps for poisonous snakes.

CONSERVATION

Land holdings of the Department of Defense are in excess of twenty-seven million acres.[56] Much of this land is held for its forest resources, some as watersheds, and some for the mineral and oil reserves. The Navy shares in the management of this vast holding with the other branches of the Military. In February 1960, overall management of renewable natural resources[57,58] of lands and water areas controlled by the Navy was transferred to the Bureau of Yards and Docks.

A survey of problems encountered in the management of natural resources of Navy-owned lands might disclose several research areas appropriate for the Laboratory. The only problems to come to the attention of the authors, however, were relatively minor or were problems more appropriately investigated at Forest Service or Fish and Wild Service Laboratories.

A single and minor example serves to illustrate one of the facets of the Navy's new responsibility. Sierra Club Conservationists disclose that erosion is severe on several Navy-held islands off the coast of Ventura County, California. Erosion is so severe on one island that it is slowly drifting into the sea. "Feral goats or domestic goats that have turned wild are going to eliminate the rare ironwood and Catalina cherry from San Clemente Island. . th of these species are found nowhere else in the world except on the Channel Islands."[59] Although prc ection of these plants is a Bureau of Yards and Docks responsibility, it is unlikely that laboratory studies would help to solve the problem.

An area of Reso rces Management that might require considerable research at NCEL is management of ocean resources The determination of responsibility among government agencies for management and guardianship of this Nation's vested interest in the natural resources of the ocean has not been delineated. Though the Departments

of Agriculture and Interior manage most of the Nation's natural resources on land, the Navy might assume this responsibility in the ocean. In the future this responsibility could well become one of the major functions of Bureau of Yards and Docks. Should the Bureau of Yards and Docks be committed to preserve and manage Natural Resources of the ocean, a great deal of research, including biological, would be required

BIOLOGICAL OCEANOGRAPHY AND MARINE BIOTECHNOLOGY

Presently, Bureau of Yards and Docks activities are primarily engaged with the design, construction, and maintenance of structures on the shores of the oceans.[60] In the future the Bureau may assume a primary responsibility for the design, construction, and maintenance of floating bases in mid-ocean and of underwater bases or structures both on the continental shelves and in the deep ocean. Seabee units will be called upon to work (Figure 28), to build, and,as their slogan goes, to fight underseas. Knowledge of the parameters of the ocean, both physical and biological, will be essential for Bureau of Yards and Docks activities to fulfill their many new responsibilities.

The present interest in the oceans and the acute awareness of the role that the ocean will play in national defense has served to accentuate our ignorance of the major portion of the earth's surface. Indeed, this lack of knowledge is preeminent with respect to biological oceanography. Historically the dilemma is somewhat analogous to our lack of knowledge of the effects of fungi upon military materials in the Pacific operations of World War II. Millions of dollars worth of materials were damaged beyond use because of unwise choice of materials, lack of appropriate protective treatments, improper packaging, transportation, unloading, storage and maintenance. Greathouse and Wessel[41] in "Deterioration of Materials" state, . . ."practically every one was unaware of the problems which were bound to arise. Only through experience, loss of manpower and materials, guesses as to ways of preventing the damage, experimental study of the problems, modification of specifications, as much as sweat and worry, were the problems finally met and, in great measure, overcome."

Ultimately the ocean may be a friend or foe depending on our knowledge of the relationship of organisms to their marine environment, to one another, to man, and to structures placed in the ocean. The possibility and probability of military construction in the hydrosphere implies a basic responsibility of the Bureau of Yards and Docks. The Bureau should initiate programs designed to study the pertinent biological relationships.

The Effect of Marine Organism on Deep Ocean Structures. One of the dominant effects of the biological parameter on ocean installation is that of fouling. Well known is the economic and strategic effects of fouling on vessel motility. Protection of ships hulls for 24-month periods through the application of antifouling coatings is now possible. That this information and the materials used will likewise be efficient at depths where different fouling organisms may exist is not known. Furthermore, the undersea installations conceivably will be in waters for a period of time much in excess of 24 months. Fouling also interferes with underwater sound transmitting and detecting devices, reduces the flow of liquids in pipes and conduits. It may well render sensitive instruments as gauges, cameras, regulating devices, trigger-actuating mechanisms, and monitoring devices inaccurate or inoperative. Of great relevancy is the knowledge that fouling may hasten corrosion and subsequent weakening of underwater structural members. Finally, the growth of fouling organisms by their sheer bulk can, in short order, engulf an underwater structure or device under tons of living debris. (The latter phenomenon, however, is more likely to occur in shallow water on the continental shelves than in the deep cold water of the ocean basins.)

The effect of bottom sediments on ocean structures is also of prime concern. ZoBell has found bacterial populations of a few thousand to 500,000,000 per gram of ocean sediment. Drew reports an average of 160,000,000 bacteria per gram of ocean mud from the sea floor near the West Indies. Recently, S. Meyer of the University of Miami reported that a mixed culture of bacteria from ocean sediments produced a weight loss of a metal coupon of 37 mg. per square decimeter in 14 days. In the anaerobic or reducing environment that characterize the marine muds, the bacteria also tend to attack a wide range of organic matter. Recent investigations at this Laboratory[61] illustrate the extreme versatility of deep ocean bacteria in attacking organic materials. The above facts would justify an investigation of the activities of microorganisms at the ocean floor, a possible site of construction.

Marine microbiology is a grossly neglected subject. At the 1953 International Congress of Microbiology in Rome, at which Marine Microbiology was accorded a sectional status for the first time, less than 30 of the more than 5,000 registrants indicated an interest in the sea. The known species of bacteria is approximately 1,600 and of these approximately 100 are marine--from 70 percent of the earth's surface. Furthermore, we know but little of the distribution of these organisms. They are commonly found absorbed to aggregates of organic matter in the

sea rather than free swimming. Might we expect that underseas installations may increase the concentration of organic matter and thus microbial populations and activities.

A study of the effect of marine organisms on engineering materials in the deep ocean[62] has been an integral part of the research program at this Laboratory for several years. The fruitful studies are establishing the U. S. Naval Civil Engineering Laboratory as a leader in this area of undersea technology and have already materially altered thinking concerning the use of some materials, for example acrylic resins, in a deep ocean environment. Testing and evaluation of various materials in the deep ocean (Figures 31 and 32), however, is just beginning. For the successful implementation of Bureau of Yards and Docks function, it is not only necessary that this fruitful study be continued, but that it be expanded.

<u>Oceanic Distributions of Chemicals of Biological Origin</u>. In sea water there are many substances that are continually being produced by some living organisms and utilized by others. Their concentrations depends upon the relative rates of production and consumption, and hence by the relative abundance and activity of various members of a complex biological community. The presence or absence of certain of these metabolites may itself determine whether or not a given species of the biological complex can live in a certain part of the ocean. Therefore, the concentration and distribution of the biometabolites should parallel the distribution of various marine organisms.

Some of the better known biometabolites in sea water are oxygen, carbon-dioxide, ammonia, hydrogen sulfide, nitrates, phosphates, and silicates. Others, about which less is known, are marsh gas, carbon monoxide, hydrogen, and the thousands of organic compounds that arise from the decay of plant and animal life. The latter compounds may uniquely earmark the location of specific biological communities.

Many of the biometabolites dissolved in sea water are either gases or volatile organic compounds and of these, oxygen has been most widely studied, though sampling at great depths is slow and costly and even data concerning the distribution of oxygen is meager. Data concerning the distribution of hydrogen sulfide, ammonia, and other gases are even more limited, and composition and concentration of volatile organic compounds in sea water is almost totally unknown.

Most of the known data concerning the concentration of various gases in sea water were collected by analyzing samples of water drawn from various depths. Chemical methods of analyses have usually been used and sampling has been accomplished by lowering small bottles into the ocean. The bottles are filled underwater and then drawn to the surface by means of a rope or line. Such methods are not only cumbersome but are subject to even more serious defects. From the moment the sample of water is trapped to the time when it is analyzed, considerable time ensues and during this period the composition and concentration of gases in the sample changes. Furthermore, gases are apt to be lost or gained when the sample bottle is opened.

Instruments are being developed for in situ determination of oxygen concentrations at various depths. Contrary to claims by manufacturers, reading on these instruments are influenced by pressure and temperature and are not suitable for measurements at greater depths than a few hundred feet. Furthermore, only oxygen concentration is determined. An area of research suitable for the Laboratory is the development of methods for constant analysis of streams of water pumped from various depths in the ocean.

The feasibility of pumping sea water from great depths was demonstrated by the Department of Oceanography at Texas A. and M. University.[63] Pumping from a depth of 3700 meters in the "Sigsbee Deep" was apparently continued for several days at a rate of 125 gallons per hour and, during this time, several thousand gallons of water were obtained. Part of the water thus obtained was circulated through countercurrent liquid:liquid extraction apparatus. Petroleum ether was the solvent used and the lipids extracted were saved for C^{14} dating. Fewer problems were encountered in pumping the water than in extracting with petroleum ether.

A liquid:gas countercurrent exchanger (or extractor) would be more useful than a liquid:liquid extractor in studying the distribution of gaseous metabolities in sea water. The difficulties in handling a volatile liquid as petroleum ether would, furthermore, not be encountered in this technique.

The metabolic products of living organisms and the organisms themselves both influence the deterioration of structural materials. As justification for research in the above cited area, awareness of the concentration and distribution of metabolic products should aid considerably in the selection of suitable materials for use in specific locations in the ocean. The distribution of biological communities (which produce carbon monoxide gas) influence transmission of sonar

signals, is indicative of the location of food resources, and possibly on the location of oil and mineral resources. It is probable that the composition of biometabolites in the ocean is greatly influenced by the composition of adjacent muds and soils. The presence of specific biometabolites or hydrogen gas might even indicate the disposal of wastes or discharge of waste gases from passing submarines. Finally knowledge of the distribution and concentration of oxygen might indicate a possible source of oxygen for underwater workers.

Undersea Air Supply. Before underwater structures can be occupied by man, a dependable system must be devised for supplying him with air. Design of that system should not be deferred until after the structures have been erected, as the design of a system for maintaining an habitable atmosphere within underwater structures may be more challenging and time consuming than the design of the structures themselves.

During the design and construction of the Nautilus, all efforts were concentrated on the development of the nuclear power system and the hull of the submarine. When launched, apparently her sole supply of oxygen, save an emergency supply of oxygen candles, was the air within her large hull. In the televised showing of her first round-the-world cruise she was still relying on oxygen candles, thus, she must have traveled with her snorkel out of water throughout most the journey. Even today, nuclear powered submarines apparently still depend somewhat on oxygen candles or on tanks of compressed air and oxygen. At a recent conference[64] on "Toxicology in the Closed Ecological System" it was stated that the electrolytic generators produce only about half of the oxygen required by submarine crews.

Potentially, one of the most dependable and practical methods for bringing air to an underwater structure is via a pipeline from a shore based pumping station. Where bottom topography permits, such methods are feasible even where underwater structures are a considerable distance from the shore for gas can be piped great distances without difficulty.

A less dependable though perhaps more practical method for bringing air to underwater structures is through a hose from a floating pumping station. Lack of dependability of floating pumping stations was illustrated by the recent "sea lab" trials near Bermuda.[65,66] A storm interrupted the trials and nearly caused a tragedy insofar as the surface vessel supplying the vital mixture of oxygen and helium could not operate during a storm. A manned underwater structure cannot rely upon air pumped from the surface as its sole source of oxygen. Surface pumping stations, however, are certainly very practical as components of a "redundant" complex of several devices for supplying air and oxygen to the submerged structures.

When sufficient power is available, oxygen can be generated by the electrolysis of sea water. At the present time, electrolytic generators though not without faults, are the most highly developed devices for supplying oxygen underwater. They supply no nitrogen and do not remove carbon dioxide and other toxic gases produced in a closed environment. The nitrogen component of the air that escapes or that is used for such purposes as operating air locks or for charging scuba tanks, cannot be replaced by the electrolysis of water. Furthermore, considerable auxiliary air processing equipment is required to remove hydrogen, carbon dioxide, and other toxic gases. Efforts to improve electrolytic oxygen generators and the accompanying air processing equipment appear to be reaching a point of diminishing returns and further development of improvements will no doubt be very costly.

The earth's atmosphere is revitalized by the photosynthetic activity of green plants, which produce oxygen and consume carbon dioxide. A number of laboratories[67,68] are attempting to imitate nature by employing photosynthetic gas exchangers for revitalizing submarine atmospheres. Mass cultures of algae are grown under artificial light, and the air to be purified is bubbled through the cultures.

Though such exchangers very effectively perform the desired exchange of gases, they require the expenditure of around 30 kilowatts of power per man just for the photosynthetic process. Additional power is required for circulating water and processing the air. The abnormally high consumption of power is required in consequence of the limited efficiency in the conversion of electrical energy to light energy. For space travel the latter problem would not be encountered as sunlight would be employed in lieu of artificial light. Unless far more efficient means are found for converting electrical energy to light energy, however, the use of photosynthetic gas exchangers for ventilating underwater structures does not appear to be practical.

The feasibility of utilizing the air dissolved in sea water as a source of oxygen for manned underwater structures, and subsequently utilizing the deoxygenated sea water as a vehicle to remove waste gases, is being studied at the General Electric Research Laboratory[69] and at the U. S. Naval Civil Engineering Laboratory.[70,71] The former laboratory is testing devices for bringing about an exchange of gases through a special membrane; whereas the U. S. Naval Civil Engineering Laboratory is testing simple devices for effecting an exchange of gases by bringing the sea water and air into immediate contact in the form of a finely dispersed mixture. The advantage of the membrane process is that relatively little

energy is required. In the second process, however, the desired exchange of gases occurs almost instantaneously and large volumes of water can be processed with relatively compact equipment.

At the General Electric Laboratory small rodents have been kept alive for nearly two weeks in a submerged chamber ventilated via a thin silicone rubber membrane. The membrane permits the passage of oxygen, carbon dioxide, nitrogen, and water vapor, but does not permit passage of water. In one experiment the top and bottom of a box or cage containing a mouse were covered with a one-mil silicone rubber membrane. "The entire cage was immersed in a large tank and stirring motors kept the water moving past the membrane. A mouse was contained inside the cage. Ordinarily he would have lowered the O_2 pressure approximately 2% per hour. The O_2 concentration was monitored continously, and the air was sampled for CO_2 content. This apparatus operated successfully for four days with the O_2 content at 14-15% and the CO_2 content approximately 1%. During this time the mouse appeared to behave in an ordinary manner. His water was supplied by a copper cooling coil which condensed water that had permeated the membrane. After four days, mold was beginning to form on food which had become soaked, and for this reason the test was terminated.[69]

A laboratory model of a "venturi gas exchanger," recently constructed at NCEL, "renews" or "revitalizes" air in a chamber in which a small animal (Figures 33 and 34) or a small flame (Figure 35) is maintained. Stale air is pumped from the chamber by means of a venturi pump, also called a venturi ejector, and then forced through the gas exchanger where the air is continuously scrubbed in a stream of sea water. Gases from the chamber and the gases dissolved in the sea water freely mix and interchange. Excess carbon dioxide in the stale air diffuses into the stream of sea water and oxygen in the sea water diffuses into the oxygen-deficient stale air. The scrubbed and revitalized air is then returned to the chamber where it can again be used by the animal or flame.

The flame of a laboratory microburner can be kept burning indefinitely by means of the venturi gas exchanger; and on several occasions a pair of rats, suffering no ill effects, have been maintained in the apparatus throughout an entire eight hour day. The only source of oxygen for the rats or for the flame was the dissolved air removed from the sea water.

From data obtained in experiments with the venturi gas exchanger, it was calculated that the microburner consumed oxygen at a rate of four to five liters per hour, or at about one fifth the rate at which man

consumes oxygen. It was estimated that about 40 percent of the dissolved oxygen was removed from the sea water. At the same rate of oxygen removal, it would be necessary to process about 40 gallons of air-saturated sea water per minute to supply one man with oxygen.

With but little modification, the device described could be employed to supply men working in "soft shelled" structures or suits at depths of up to about 100 feet. Such depths occur in much of the North Sea, the gulf of Mexico, and the Bering Straits; all areas of considerable under-sea activity. A commercially available 5 horsepower submersible pump has the capacity to operate an estimated 2-5 man unit at a depth of 60 feet. An air pump would also be required to pump the air from the gas exchanger, which would be operated at an internal pressure of one atmosphere or less, up to submergence pressure.

At depths greater than 100 feet, the device, as now designed, could be employed only with "hard shelled" structures or suits, as at submergence pressures existing at greater depths, nitrogen narcosis would be encountered. For use at depths of greater than about 100 feet, the Venturi gas exchanger is perceived as only one component of a complete system for ventilating underwater structures. Eventually an air separator, a pressure-reducing pump, and other components would also be required. Continued research is required to improve the Venturi gas exchanger and to develop an air separator and a pressure-reducing pump.

Anaerobic Biochemical Fuel Cells. Very large scale requirements for power underwater can be met by nuclear power stations; very small, by tiny batteries powered by radioactive isotopes; but the outlook for underwater power sources of the order of one to ten horsepower is less promising.

Iron powder might be burned with sulfur to produce heat for steam generators. Iron and sulfur are both compact in volume and both are inexpensive. On a weight basis, however, the combustion of iron with sulfur produces considerably less heat than is produced when coal is burned in air. Furthermore, combustion products of the iron and sulfur reaction are solid rather than gaseous and would therefore be more difficult to discharge.

Fuel cells have been suggested as a means for obtaining power underwater, but insofar as they require oxygen, and as oxygen is in short supply underwater, fuel cells are no more feasible than internal combustion engines. Oxidants other than gaseous oxygen are now being considered for use in fuel cells but the same oxidants might also be employed in internal combustion engines.

It is conceivable that anaerobic biochemical fuel cells that consume iron and hydrocarbons for fuel, and sulfate ions in the sea water in lieu of oxygen, will someday be developed. Numerous marine bacteria can utilize sulfate ions in lieu of molecular oxygen to oxidize their food stuffs, and there are three times as many sulfate ions in one liter of sea water as their are molecules of oxygen in one liter of air. Furthermore, each of the sulfate ions contains twice as many oxygen atoms as are contained in one molecule of oxygen. At least 37 terrestrial bacteria are being considered for use in biochemical fuel cells, but few, if any, marine organisms are being considered for this purpose. The most prominent scientists interviewed for this report were somewhat skeptical that research in this area would yield an early return for investments. However, anaerobic biochemical fuel cells may ultimately revolutionize undersea technology.

Luminescense of Marine Organisms. Most of the luminescent organisms are marine and they include bacteria, protozoa, other invertebrates and vertebrates. That such organisms are present in significant numbers is demonstrable at Phosphorescent Bay, a Puerto Rican tourist attraction. The mechanical agitation of a ship's wake engenders light sufficiently bright to enable passengers to read newspapers. Troop and equipment landing boats of World War II were identified by similar bright wakes in darkness and subsequently sunk. It is conceivable that concentrations of bioluminescent organisms might indicate the presence and location of underwater installations. Man might use the same organisms as an underwater source of inexpensive and non-dangerous illumination.

Biological Methods to Predict Ice Break-up. The practical importance of predicting the break-up of polar ice increases each year, for the strategic importance of the polar regions is growing. Just as weather forecasts are of great importance to farmers, forecasts of ice conditions and ice break-up are of great importance to ships captains plying polar seas, pilots seeking landings on sea ice, and vehicle operators attempting to cross the polar ice. Recently a Navy-owned tractor broke through the ice at McMurdo Sound and, fortunately, the vehicle operator was saved and the tractor was recovered from the fifty feet of water in which it sank. Accidents on ice do not always have as happy an ending, however, and many individuals have lost their lives when an unexpected break occurred.

For some years, Russian scientists[72,73] have established crude predictions of ice break-up based on the composition of the plankton. "Blooming" of plankton at the ice edge is said to be a condition of "spring" characterized by the opening of the ice after a long polar

winter. It is commonly held opinion that the sudden blooming of phytoplankton is triggered by the release of nutrients into the water from the ice. A short distance from the edge of the ice or slightly later in the season, zooplankton is more abundant, and as time passes the total abundance of plankton diminishes and the relative abundances of various planktonic species change. A ship's captain fortunate enough to have a trained biologist aboard can make some crude estimates of the distance between his ship and the edge of the sea ice or the elapsed period of time since the ice melted in the vicinity.

The United States is also pursuing studies[74] of the distribution of plankton in polar seas and of the relation of the plankton to the sea ice. In the summer of 1960, Dr. Sidney Galler, Director, Biology Branch of the Office of Naval Research, collaborated with scientists at Woods Hole and Texas on the design of an automatic plankton sampler which was installed on the Navy submersible, the "Sea Dragon." Analysis and interpretation of samples obtained in arctic seas with the Galler-Vine-Rather automatic sampler are being performed at the University of Southern California.

Mr. Earl H. Moser, Director, Polar Division, NCEL, has discussed the possibility of predicting the time polar ice would break up by observing plankton and sea life under the ice. Mr. Moser suggests a possibility that algae trapped in the ice might, in some manner, indicate the areas where breaking will first occur. He has noted that the amount of algae in the ice varies considerably.

The senior author has discussed this problem with Dr. Bunce, Lamont Geological Observatory, Palisades, New York. Dr. Bunce has studied the algae in the ice at McMurdo Sound, and is of the impression such studies might indeed lead to methods for predicting breakage. He states that sea ice can be described as consisting of three layers. The upper layer consists of snow and ice, the main layer of very solid clear ice, and the under layer is softer and more porous. The under layer contains the algae, and prior to the ice breakage, the under layer melts off, perhaps producing a marked increase in the quantity of algae in the sea water under the ice.

Studies of algae in sea ice at Devon Island in Northern Canada, being sponsored by the Arctic Institute[75] reveal that algae are not merely trapped in the ice, but grow and multiply in the layer of ice adjacent to the water. The algae are unique in that they represent the extreme

adaptation of plants to low temperatures (maximum about -1.68° C.) and the extreme adaptation of green plants to low light intensities. If the snow covering the ice is removed during the daylight season, the intensity of light penetrating the ice is greatly increased, and the algae immediately disappear. Though the added sunlight also causes the ice adjacent to the water to thaw, the disappearance of algae precedes any observable structural change in the crystal structure of the ice.

In summary, a means to accurately forecast the break up of polar ice would be a distinct boon to Bureau of Yards and Docks Activities located in polar regions. There is a distinct possibility that methods of predicting break up of sea ice can be developed through a study of algae growing in the ice.

Kelp Beds as Floating Breakwaters. It will be less difficult to perform useful work from a mid-ocean platform if a means can be found to reduce incident waves and currents. Considerable thought and experimentation has been directed toward the design of floating breakwaters to temper wave motion in open areas of the sea, but thus far the effort has not been very fruitful. The most significant construction was that off Normandy, France, during World War II when about 50 cruciform steel barges were moored in about 400 feet of water to form a line approximately one mile long as partial protection for amphibious landings at Arromanches and St. Laurent. Two weeks later, during a storm the barges broke loose from their moorings and caused considerable damage to neighboring structures. They were generally judged unsuccessful.

It may be feasible to develop a relatively inexpensive breakwater with sea weeds suspended on a lightweight floating net. Though sea weeds normally grow in shallow water from rocks on the sea floor, they can be grown readily on bamboo sticks, wires or nets. In Japan, large "kelp gardens" are grown from huge floating nets and harvesting consists of rolling up the nets, hauling them ashore and removing the kelp by hand.

One difficulty in the construction of a sea weed breakwater would be that of anchorage. To be effective in attenuating wave action, the nets with the attached sea weeds must extend a distance of 1,000 feet or more horizontally and a depth of 50 feet or more vertically. During a storm, tremendous mooring forces would be exerted on a kelp bed of such dimensions; for, in a relatively calm sea, mooring forces of 60 pounds have been measured from a single kelp plant attached to a spring scale. Anchorage of the net to the floating platform would tend to reduce mooring forces, but perhaps at the expense of wave attenuation due to net wave

movement. If, during a storm, the sea weeds should wash into the platform, they could be towed back in place after the storm. At any rate, it is unlikely that any work from the platform would even be attempted during a storm.

It is very likely that sea weeds would be torn from the nets during a storm though Dr. Wheeler J. North of the California Institute of Technology, Associate Professor of Environmental Health Engineering and eminent alogist, believes that this would constitute but a minor difficulty. Dr. North is of the opinion that growth of new sea weeds would soon compensate for losses during inclement weather and that, with the correct choice of plants and conditions, a six month growth on the nets would be sufficient to weather most storms.

Dr. North had significant reservations, however, concerning the amount of protection that an aggregate of sea weeds would provide. He has observed that kelp beds retard the short period choppy waves (sea) but not those of longer periods (swell). The authors likewise observed the behavior of wave amidst several kelp beds off the coast of State Highway Number One in central California and found the statements of Dr. North are amply verified. The long period waves passed through the kelp beds as though the kelp were not there, but the short chop was absent within and in the lee of the kelp beds for some distance shoreward.

In summary, kelp beds could probably be grown from floating nets. Whether they could provide significant protection to floating platforms some distances from shore, however, is a moot question dependent on wave-net dimensions. Since single kelp plants induced mooring forces of sixty pounds, kelp beds could significantly attenuate water movement in their lee. Sea weed breakwaters, however, likely would attenuate the short period waves (chop) but would have little influence on those of longer period swell unless the beds were immensely large.

Deep-Sea Life as Design Guide. "Nature has had millions of years of experience in designing appropriate shapes for existence in deep-sea environments. Man has already adapted some of these shapes, as in the submarine and bathyscaphe, for intrusion into the deep ocean. Further study of the shapes of deep-ocean animals and plants may lead to configurations for constructing, placing, and maintaining installations in the ocean depths."[76]

Study of the design and function of sea life might also lead to

concepts for new types of ocean bottom vehicles. For example, many features of form and modus operandi of the star fish might be adapted to the construction of a tractor for crawling about the continental shelves.

Training of Sea Mammals. The high degree of intelligence of porpoises and other sea mammals has long been known to professional animal trainers, and there is a distinct possibility that sea mammals can be trained to assist man engaged in undersea activities. Several marine laboratories in California and Florida are currently exploring this possibility and have succeeded in training porpoises to retrieve objects from the water and to carry guide lines to distant divers theoretically lost in the ocean. Porpoises have also been trained to carry swimmers rapidly about in the water.

The possibility and probability of military construction in mid-ocean, on the continental shelves, and in the deep-ocean portend of a future theatre of operations for Seabees. Personnel of foreign navies, of private business firms, and even hobbiests will be "running about" the continental shelves. For the welfare of the Navy, it would be highly desirable that the Seabees excel all of these in underwater skills. Trained porpoises might help them achieve such superiority. The training required would be very specialized, directed at Seabee operations, and would involve the porpoise and the Seabee.

CONCLUSIONS AND RECOMMENDATIONS

Several of the many and diverse functions under jurisdiction of the Bureau are in areas in which biological research can contribute significantly.

Biodeterioration of Materials

From the financial consideration, the deterioration of engineering materials--an annual problem of $100,000,000 proportions--is, by far, the most significant problem facing Bureau of Yards and Docks Activities. Though the complex and intertwined biological, chemical, and physical processes involved in the deterioration of engineering materials are incompletely understood, there is ample confirmation that biological processes play an important role.

1. It is recommended that the Laboratory continue its fruitful studies of the deterioration of marine timbers but that it expand the

scope of the studies to embrace all exposed structural timbers such as utility poles, railroad ties, wharf decking, etc. Particular emphasis should be placed on the fender-pile problem.

2. It is inadvisable for the Laboratory to investigate the fungus decay of wooden buildings as a bioscience study for the problem is primarily one of design and choice of materials. Adequate microbiological research is being performed at U. S. Forest Service Laboratories.

3. It is recommended that research on the bacterial decomposition of engineering materials of organic composition be undertaken at the Laboratory. The study should embrace the deterioration of asphalt, creosote, paint, protective coatings, and plastics. Similar processes are probably involved in the deterioration of all of these materials, hence similar prevention techniques might be applicable to all. The initial question to consider is the relative importance of biological and non-biological processes. The immediate problem is to determine if these materials would deteriorate at a perceptible rate in a microbial-free environment.

4. It is recommended that field studies be conducted to compare the relative service life of paint films applied to preservative-treated and untreated wood. Oil-borne water-repellent preservatives are recommended for the study.

5. It is recommended that a minor research effort be devoted to the prevention of fungal disfigurement on asbestos shingles.

6. It is recommended that a study be undertaken at the Laboratory to elucidate mechanisms of attachment of microorganisms to submerged surfaces in sea water. The mechanisms are basic, not only to fouling, but to bacterial corrosion of iron and microbial deterioration of plastics and protective coatings.

7. It is recommended that the study of bacterial corrosion not be continued as a separate investigation but that it be incorporated with other studies at the Laboratory as the project recommenced above. It is unlikely that bacteria are involved in splash zone corrosion and it is well established that bacteria are the causative agents of anaerobic corrosion. The benefits accruing from additional study is difficult to ascertain unless means can be found to prevent attachment of bacteria to metal surfaces.

8. It is recommended that the Laboratory investigate the behavior of engineering materials in various harbor environments. Exposure tests of many types of materials should be conducted in the splash and spray zones and at several depths and locations within various Navy harbors. The program might be most efficiently conducted as an extension of the NCEL study, now underway, of the effect of a deep ocean environment on materials. Results of the exposure tests should then be correlated with the results of studies of harbor environment and harbor pollution (recommendation 2 under Sanitary Engineering).

Sanitary Engineering

The nation is engaged, by presidential decree, in its greatest efforts in history to clean up its atmosphere, its rivers, and its harbors. The Navy, as a principal user of harbors, will be one of the principal beneficiaries of the undertaking. The Laboratory can contribute to this effort by channeling a larger portion of its engineering and scientific skills to sanitary engineering research.

1. It is appropriate for the U. S. Naval Civil Engineering Laboratory to initiate studies of methods to receive sanitary wastes from ships tied up or anchored at Navy harbors. Systems in which most of the required pumps and apparatus for handling sewage were provided and maintained by shore establishments would free the ships of the need to transport additional equipment for that task.

2. It is recommended that the Laboratory survey the distribution of pollution elements in and around Naval harbors. The investigation would entail prior development of methods required for such surveys.

3. It is recommended that the Laboratory, in cooperation with District Sanitary Engineers, sponsor field studies of methods increasing load capacities of stabilization ponds.

4. It is recommended that the Laboratory investigate needs of Bureau of Yards and Docks Activities for information reports reviewing methods and equipment preventing fouling of sea water intakes.

5. It is recommended that the Laboratory maintain its position of leadership in the field of Polar Sanitation by continuing its fruitful investigations in that area.

6. It is suggested that minor investigations might be made of disposable containers for trash and garbage.

7. It is suggested that minor investigations be devoted to the identity of asphaltic compounds that frequently contaminate rainwater used for drinking purposes.

Applied Biology and Pest Control

Pest control research is, in general, of a highly specialized nature and is pursued more efficiently in specialized laboratories. Certain minor areas of investigation, associated with animal pests, could be pursued at the U. S. Naval Civil Engineering Laboratory with profit.

1. An investigation of the influence of bird droppings on engineering materials is a worthwhile undertaking for the Laboratory.

2. The design of effective traps and repellents for poisonous snakes should be considered.

Conservation

Most of the research now required by the Special Assistant for Natural Resources Management can best be performed in laboratories of the U. S. Forest Service and the U. S. Fish and Wild Life Service. If it is established that Bureau of Yards and Docks have a major responsibility toward the preservation and management of natural resources of the sea, then considerable biological research in marine conservation is required. Surveys and research are required prior to the time when conflicts of interest may arise between divergent industries.

Biological Oceanography and Marine Biotechnology

The possibility and probability of military construction in the hydrosphere implies a basic responsibility of the Bureau. To fulfill this new responsibility, the Bureau will require a thorough knowledge of the physical and biological parameters of the ocean and the relationship of these parameters to man and structures.

1. It is recommended that the Laboratory continue and expand its investigation of the effect of marine organisms on engineering materials in the deep ocean.

2. It is recommended that the Laboratory develop equipment and methods for ascertaining distribution of chemicals of biological origin in the ocean with emphasis on their distribution in the vicinity of

construction sites on the ocean floor.

3. It is recommended that the Laboratory develop several alternate methods for maintaining an habitable atmosphere for underwater breathing. The principle of redundancy should be incorporated in designing systems for supplying air to manned undersea sites.

4. It is recommended that the Laboratory undertake special research tasks in biotechnology toward increasing the capabilities of Bureau of Yards and Docks Activities in undersea and mid-ocean technology. The research recommended includes the training of sea mammals for underwater work and rescue, the development of anaerobic biochemical fuel cells, microbiological sources of luminescence, and breakwaters constructed of seaweeds.

ACKNOWLEDGMENTS

The authors wish to thank the Public Works Offices of the First, Third, and Eighth Naval Districts and the Public Works Offices of the Southwest and Atlantic Division of the Bureau of Yards and Docks for the many courtesies extended the Laboratory respresentative during his visits. The Special Assistants for Applied Biology at these offices, Mr. Fred Danos, Dr. J. H. Rehn, Mr. H. C. Secrest, Mr. Arlo Thomas, and Mr. George T. Simms, Jr., respectively, arranged for the Laboratory representative to visit Field Activities in their Districts or Divisions and escorted him on the visits.

The authors also wish to thank all of the many individuals and institutions who supplied information for this report. Their names are listed in the Appendix.

REFERENCES

1. NAVDOCKS P-164. Detailed Inventory of Naval Shore Facilities, Real Property Data. June 1964.

2. Office of Naval Research. Annual RDT&E Program Report, Naval Research Area: RR 007, Materials Sciences. 1964.

3. Office of Naval Research. Annual RDT&E Program Report, Naval Research Area: RR 005, Biological Sciences. 1964.

4. Southern Forest Experiment Station, New Orleans, Louisiana. "Covering Wood Exteriors with Asbestos-Cement Shingle Siding," by Arthur F. Verrall. June 1958. Navy Contract NY 450,020.

5. Southern Forest Experiment Station, New Orleans, Louisiana. "Condensation and Decay Problems Connected with Cold Storage Rooms," by Arthur F. Verrall. June 1958. Navy Contract NY 450,020.

6. Southern Forest Experiment Station, New Orleans, Louisiana. "The Effect of Roof Overhang on the Deterioration of Wooden Walls," by Arthur F. Verrall. July 1959. Navy Contract NY 450,020.

7. Southern Forest Experiment Station, New Orleans, Louisiana. "Condensation in Air-Cooled Buildings," by Arthur F. Verrall. December 1961. Navy Contract Y-R007-08-201.

8. Southern Forest Experiment Station, New Orleans, Louisiana, "Studies of Factors Influencing Rainwetting of Siding," by Arthur F. Verrall. May 1963. Navy Contract Y-R007-08-201.

9. William F. Clapp Laboratories, Inc., Duxbury, Massachusetts. Report No. 11044. Twelfth progress report on marine borer activity in test boards operated during 1958, by Dorothy Brown Wallour. 15 March 1959. Navy Contract NBy-17810.

10. The Marine Laboratory, University of Miami, Florida. Report ML 60106. Marine Borer Investigations-Final Report, F. G. Walton Smith, Director. May 1960. Navy Contract NBy-81879.

11. Hochman, H., and H. Vind. "Limnoria vs. Creosote-Treated Piling," BUDOCKS Technical Digest, No. 71, Oct. 1956, p. 18.

12. U. S. Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. Technical Report R-188, An Evaluation of Organotin Compounds

as Preservatives for Marine Timbers, by H. P. Vind and H. Hochman. 19 March 1962.

13. NCEL. Technical Reports R-027, R-077, R-147, R-184, and R-236; Harbor Screening Tests of Marine Borer Inhibitors--I, II, III, IV, and V; by H. Hochman and T. Roe, Jr.; 9 July 1959, 16 March 1960, 16 May 1961, 13 February 1962, and 22 February 1963.

14. O'Neill, Thomas B., R. W. Drisko, and H. Hochman. "Pseudomonas creosotensis sp. n., a Creosote Tolerant Marine Bacterium," Applied Microbiology, Vol. 9, November 1961, p. 472.

15. NCEL, Technical Report R-243, A Comparison of the TEG-F, Chromatographic, and Spectrophotometric Methods of Creosote Analysis, by R. W. Drisko, 13 June 1963.

16. Military Specification P-23613 (Docks). Piles, Wood, Pressure Treated, Marine; Douglas Fir and Southern Pine. 26 March 1963.

17. American Wood Preservers Institute. "Navy Specifies AWPI Quality Marked Marine Piles," Wood Preserving News, September 1963, p. 9.

18. Wright, Kenneth E. "Navy Requirements for Wood Products," Navy Civil Engineer, Vol. 4, No. 2, February 1963, p. 15.

19. Moe, Alfred B. "Effective Objective Painting," Navy Civil Engineer, Vol. 7, No. 7, July 1963, p. 36.

20. Ross, Richard T. "Microbial Deterioration of Paint Films," Developments in Industrial Microbiology, Vol. 6, Supplement, August 1964, p.14.

21. Office of Naval Research, Symposium Report ACR-84; Navy-Wide Workshop in Biological Sciences Research; National Naval Medical Center, Bethesda, Maryland, 14-18 October 1963.

22. Traxler, N. R. "Durability of Asphalt Cements," Proceedings of the Association of Asphalt Paving Technologists, Vol. 32, San Francisco Meeting, 18-20 February 1963, p. 44.

23. Dirscherl, Wilhelm. "The Formation of Acetylmethylcarbinol from Acetaldehyde and from Pyruvic Acid by Irradiation with Ultra-violet Light,"

Z. Physiol. Chem., Vol. 188, 1930, p. 225-46. Abstracted in Chemical Abstracts, 24:3212.

24. Langenbeck, Wolfgang, H. Wrede, and W. Schlockerman. "Carboxylase," Z. Physiol. Chem., Vol. 227, 1934, p. 263-276. Abstracted in Chemical Abstracts, 28:7271

25. Tomiyasu, Yukio. "Existence of Carboligase," Journal Agricultural Chemical Society of Japan, Vol. 12, 1936, pp. 1132-48. Abstracted in Chemical Abstracts, 31:2240

26. Hundeshagen, R., Bautenschutz, 6, 1936, p. 141.

27. Harris, J. O. "Bacterial-Environmental Interactions in Corrosion of Pipelines-Ecological Analysis." National Association of Corrosion Engineers, Conference, Chicago, Illinois, 1964.

28. Traxler, R. W. "Microbial Degradation of Asphalt," Biotechnology and Bioengineering, Vol. IV, 1962, pp. 360-376.

29. Phillips, U. A. and R. W. Traxler, "Microbial Degradation of Asphalt," J. Applied Microbiology, Vol. 11, No. 3, May 1963, pp. 235-238.

30. Burgess, S. J., Highway Research Board, Bulletin, 1956, p. 118.

31. Kulman, F. E., Corrosion, Vol. 14, 1958, p. 23.

32. Martin, K. G., Division of Building Research. Technical Paper 11, Commonwealth of Science and Industry Research Organization, Australia, 1961.

33. Volkova, V. D., Avtom Dorgi (Moscow), Vol. 21, 1958, p. 25.

34. King and Garvaris, Consulting Engineers, New York. "Restudy of Existing Sheet Pile Bulkhead, Naval Air Station, Floyd Bennett Field, N. Y." 6 November 1963. Navy Contract NBy-50996 (A&E).

35. Updegraff, David M. "Microbiological Corrosion of Iron and Steel." Corrosion, Vol. 11, No. 10, October 1955, pp. 422t-446t.

36. ZoBell, C. E. and Sydney C. Rittenberg. "Sulfate-reducing Bacteria in Marine Sediments." J. Marine Research, Vol. 7, 1948, pp. 602-617.

37. District Public Works Offices, Fifth Naval District, Norfolk, Virginia. Report: Deterioration of Precast Reinforced Concrete Piles in Marine Environment at the Norfolk Naval Shipyard, Naval Hospital and Naval Ammunition Depot, St. Juliens Creek, Portsmouth, Virginia, May 1959.

38. NCEL. Technical Report R-315. "An Inflatable Causeway," by J. J. Hromadik, J. J. Traffalis, and R. A. Bliss, 18 August 1964.

39. Skerman, T. M., "The Nature and Development of Primary Films on Surfaces Submerged in the Sea." New Zealand Journal of Science and Technology, Vol. 38 B, July 1956.

40. Mechalas, Byron J., Research Microbiologist, Aerojet-General Corporation, Azusa, California. Private communications.

41. Greathouse, Glenn A. and Carl J. Wessel. "Deterioration of Materials--Causes and Preventive Techniques." A collaboration of the Department of Defense and the Prevention of Deterioration Center, National Academy of Sciences, National Research Council. New York, Reinhold Publishing Corporation, 1954.

42. District Public Works Office, First Naval District, Boston, Massachusetts. Report of Investigation of Pollution of Narragansett Bay by Raw Sewage Discharged from Naval Vessels," by Special Assistant for Sanitary Engineering, July 1960.

43. State Water Quality Control Board, State of California. Publication No. 26: "An Investigation of the Effects of Discharged Wastes on Kelp." 1964.

44. Lau, Edward F. C., "An Engineered Method of Sewage Treatment." Navy Civil Engineer, April 1963, p. 20.

45. NCEL. Technical Report R-256. Survival of Sewage Bacteria in Zero-centigrade Sea Water, by J. E. Halton and W. R. Nehlsen, 30 June 1963.

46. Clark, Lloyd K., "Engineering Aspects of Arctic and Sub-arctic Sanitation." Paper presented at AAAS Meeting, Alaskan Division, University of Alaska, 31 August to 5 September 1964.

47. NCEL. Technical Note N-476, A Development Program for Polar Camp Sanitation, by W. R. Nehlsen, 28 December 1962.

48. Guzman, Ramon M., "Rain Catchment Basins in the Caribbean." American Waterworks Association Journal, Vol. 51, 1959, p. 399.

49. Turner, H. J., Jr., D. M. Reynolds, and A. C. Redfield. "Chlorine and Sodium Pentachlorophenate as Fouling Preventives in Sea Water Conduits." Industrial and Engineering Chemistry, Vol. 40, March 1948, p. 450.

50. Chadwick, W. L., F. S. Clark, and D. L. Fox. "Thermal Control of Marine Fouling at Redondo Steam Station of the Southern California Edison Company." Transactions of the American Society of Mechanical Engineers, Vol. 72, No. 2, February 1950, pp. 127-132.

51. Castle, Edward S., "Electrical Control of Marine Fouling," Contribution from Woods Hole Oceanography Institution, Woods Hole, Massachusetts. 15 May 1950.

52. U. S. Department of Interior, Bureau of Sport Fisheries and Wildlife. Progress Report for 1 April 1962 to 30 June 1963. "Biological Studies of the Problems of Bird Hazard to Aircraft." (AD 604 442).

53. Contract NBy-53155, Final Report. Contractor: University of Hawaii. "Studies on Effects of Sonic Stimuli on Flying Albatrosses at Midway Island." June 1963, May 1964, by Hubert Frings and Gordon W. Boudreau. 31 May 1964.

54. Fish and Wildlife Service, U. S. Department of the Interior. Wildlife Leaflet 345. "Control of Snakes," by William H. Stickel, June 1953.

55. Thai Red Cross Society. Pamphlet: "Snake Farm." Edited by W. T. Yip. Printed and Published by Thummada Press, Bangkok, Thailand, 1964.

56. Swingler, W. S., "Forestry Management Assistance," Navy Civil Engineer, Vol. 4, No. 1, January 1963, p. 26.

57. Department of the Navy, Bureau of Yards and Docks, "The Bureau of Yards and Docks in the First Four Years of the Space Age-1958-1961."

58. Zirzow, CDR C. F. (CEC, USN). "Our Role in Natural Resources Management," Navy Civil Engineer, Vol. 3, No. 2, February 1963, p. 28.

59. Sierra Club, Mills Tower, San Francisco. Press Release: "Remove Sheep From San Miguel Island, Botanists Urge." (Refers to Dr. Louis K. Wheeler, Professor of Botany, University of Southern California). 11 June 1962.

60. Department of the Navy, Bureau of Yards and Docks. "Precepts." October 1963.

61. NCEL. Technical Report R-329, Deep-Ocean Biodeterioration of Materials--Part I, by J. S. Muraoka, November 1964.

62. NCEL. Technical Report R-182, The Effects of Marine Organisms on Engineering Materials for Deep-Ocean Use, by J. S. Muraoka, March 1962.

63. Hood, Donald, "Cruise 62-H-13, Deep Water Sampling of the Sigsbee Deep, Texas Agricultural and Mechanical University. Internal Report.

64. U. S. Navy Special Projects Office and the Lockheed Missiles and Space Company. A Symposium on Toxicity in the Closed Ecological System, Edited by McHonma and J. J. Crosby. (Symposium was held July 29-31, 1963, in Palo Alto, California).

65. "Log of the Aquanauts," Naval Research Reviews, September 1964, pp. 16-24. Vol. XVII, No. 9.

66. "Sealab I," Naval Research Reviews, July 1964, pp. 5-9, Vol. XVII, No. 7.

67. School of Aviation Medicine, Randolph AFB, Texas. No. 58-126. "The Provision of Respiratory Gas Exchange for Small Primates by Use of a Photosynthetic Gas Exchanger," by Robert D. Gafford, CAPT. USAF; H. L. Bitter, CAPT., USAF; and Robert M. Adams, M. A.

68. NRL Report 5954. "A Study of the Feasibility of Oxygen Production by Algae for Nuclear Submarines," by R. J. Hannan, R. L. Shuler, and C. Patouillet, 12 August 1963.

69. Robb, Walter, General Electric Research Laboratory, Schnectady, New York. "Air Ecology Using Thin Silicone Membrane in an Aqueous Environment." A paper presented before the New York State Medical Society, 16 February 1965.

70. NCEL. Technical Note N-543, A Proposed System for Supplying Air to a Hypothetical Underocean Seabee Base, by Harold P. Vind and Mary Jane Noonan, 8 November 1963.

71. NCEL. Technical Note N-734. A Proposed System for Supplying Air to

a Hypothetical Underocean Seabee Base. II. The Venturi Gas Exchanger, by Harold P. Vind and Arthur Langguth, 16 June 1965.

72. Laktionov, A. F., "On the Methods of Ice Forecasting According to Plankton." Problemy Arktiki, No. 9, 1940, pp. 27-34. Freely translated from Russian by Lisa Lanz with Norman J. Wilimovsky.

73. Bogorov, V. G., "Characteristics of Seasonal Occurrences of Plankton in Polar Seas and Their Importance in Ice Prediction." Contribution from the All Union Institute of Marine Fisheries and Oceanography. Zoologicheskii Zhurnal, tome 18, fasc. 5, 1939, pp. 735-747. Russian with English Summary. Translation by Lisa Lanz with Norman J. Wilimovsky.

74. Mohr, John L. and S. R. Geiger, "Comparison of Results from a New Automatic Plankton Sampler and From Conventional Methods in the Arctic Basin." Rapp. et. Proc.-Verb., Vol. 153, 1962, Cons. Internat. Explor. de la Mer. pp. 205-206.

75. Apollonio, Spencer, "Chlorophyll Content of Arctic Sea Ice," Arctic, Vol. 14, 1961, pp. 197-199.

76. NCEL. "Problems in the Field of Research and Development at the U. S. Naval Civil Engineering Laboratory,"by W. J. Christensen, Captain, CEC, USN, Commanding Officer and Director. April 1964.

Appendix

NAMES OF ACTIVITIES, INSTITUTIONS, AND INDIVIDUALS CONTACTED

The Dow Chemical Company, Midland, Michigan. A representative of the company visited the Laboratory on 31 April 1964.

Mr. C. M. Shigley, Contract Research and Development

Navy Missile Center, Point Mugu, California. Visited 7 May 1964.

Mr. George E. Mac Ginitie; Consultant, Marine Biology; Naturalist; Author; Associate Professor, retired, California Institute Technology

Mrs. George E. Mac Ginitie; Consultant, Marine Biology, Naturalist; Author.

U. S. Naval Public Works Center, San Diego, California. Visited 3 June 1964; Public Works Seminar attended.

Mr. Earl J. Kiefer, Mooring Engineer (host)

CDR Callahan, USN, Executive Officer

CDR Smith, USN, Project Manager and M. C. at seminar

Southwest Division, Bureau of Yards and Docks, San Diego, California. Visited 3 June 1964.

Mr. Arlo Thomas, Special Assistant Applied Biology

Mr. Walter Keester, Bacteriologist, Sanitary Engineering Group

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California Institute of Technology, Pasadena, California. Contacted by letters of 1 and 12 June 1964.

Dr. Wheeler J. North, Associate Professor of Environmental Health Engineering

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Pacific Division, Bureau of Yards and Docks, Pearl Harbor, Hawaii. Contacted by letters of 16 June 1964 and 14 July 1964.

Mr. Edward F. C. Lau, Division Sanitary Engineer

Civil Engineering Corps Officers School, Port Hueneme, California. Visited at NCEL, 19 July 1964.

CAPT. Jack P. Crane, USNR (attendee at summer training session)

District Public Works Office, First Naval District, Boston, Massachusetts. Visited 2-23 July 1964.

Mr. Frederick J. Danos, Special Assistant for Applied Biology (host) for visits to First Naval District Activities)

CAPT. A. F. Meeks, USN, District Public Works Officer (acting)

CDR W. C. Anderson, USN, Assistant DPWO

Mr. Jim Leahy, Director Maintenance and Control Division

Boston Naval Shipyard. Visited 20 July 1964.

CAPT. H. C. Rowe, USN, Public Works Officer

LT. J. G. Broecker, USN, Deputy PWO

Mr. L. S. Lowband, Master Mechanic, Utilities

Mr. C. Bertelli, Operator of sea water intake system and chlorination apparatus

Mr. Dave Jenkins, Head Inspection Branch, Maintenance and Control Division

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Public Works Center, U. S. Naval Air Station, Quonset Point, Rhode Island. Visited 21 July 1964.

CAPT. George Ohl, Jr., USN, Public Works Officer

CDR L. J. Padden, USN, Deputy Public Works Officer

Mr. Richard Evans, Director Maintenance Control Division

Mr. Bradbury, Head Inspection Branch

Mr. Larry Matarese, Pest Control Equipment Operator

U. S. Army Natick Laboratories, Natick, Massachusetts. Visited 21 July 1964.

Dr. Arthur M. Kaplan

U. S. Navy Public Works Center, Newport, Rhode Island. Visited 22 July 1964.

Mr. John F. Tennant, Head Maintenance Control Department

Mr. Ray G. Groff, Director Inspection Division

Mr. George Goffe, Utilities Control Division

U. S. Naval Air Station, Weymouth, Massachusetts. Visited 22 July 1964.

CDR Lanoue, USN, Public Works Officer

Mr. John Neudorfer, Supervisor General Engineer

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Visited 23-24 July 1964.

Mr. Harry J. Turner, Marine Biologist (host at Woods Hole)

Dr. Bryce Prindle, Summer Employee, Microbiologist and College Instructor

Dr. Max Blumer, Research Chemist, Department of Chemistry and Geology

Dr. Valentine Worthington, Oceanographer, author

Dr. John M. Zeigler, Soils Geologist, Chemistry-Geology Department

Dr. Stanley Watson, Marine Microbiologist

Marine Biology Laboratory, Woods Hole, Massachusetts. Visited 23 July 1964.

Dr. Albert Szent-Györgi, Nobel Laureate, Biology

Forest and Wild Life Service Laboratory, Woods Hole, Massachusetts. Visited 24 July 1964.

Mr. George Kelly, Biologist

Clapp Laboratories, Duxbury, Massachusetts. Visited 24 July 1964.

Mrs. Wallour, Marine Biologist

Mr. Ray Kennan, Marine Biologist

District Public Works Office, Third Naval District, New York, New York. Visited 27-31 July 1964.

Dr. J. H. Rehn, Special Assistant for Applied Biology (host for visits to Third Naval District Activities)

CDR A. L. Pekarsky, USN, Deputy DPWO, Acting DPWO in absence of CAPT. Kravath

CDR E. M. Michael, USN, Assistant DPWO for Facilities Management

Mr. R. W. Sherman, Special Assistant for Sanitary Engineering

CDR J. P. Marron, USN, Assistant DPWO for Facilities Engineering

Mr. J. Malone, Construction Management Engineer

Mr. Al Kerner, Project Management Engineer

Mr. H. Baker, Director, Construction Division

Mr. George Brown, Construction Management Engineer

Mr. Gordon Wallace, Chief of Design Division

Mr. J. Picco, Director Maintenance Division

U. S. Naval Applied Science Laboratory (BUSHIPS), U. S. Naval Base, Brooklyn, New York. Visited 28 July 1964.

Mr. Hyman Lacks, Head Coatings Branch

Mr. Walter Miller, Chemist, Section Leader

Mr. Eugene Fisher, Marine Microbiologist

Mr. Arnold Fryberg, Graduate Student in Marine Biology

Mr. I. Geld, Inorganic Chemist

Mr. S. Tudor, Chemist

New York City Aquarium, Coney Island, New York. Visited 28 July 1964.

Mr. C. P. Cologer, Materials Biologist (employed by U. S. Naval Science Laboratory--utilities facilities of New York Aquarium)

Mr. Jack Lelertori, Marine Biologist, Graduate Student for Dr. Nigreli, at New York City Aquarium and half days for the U. S. Naval Applied Science Laboratory--assists Mr. Cologer

Dr. Christopher Coates, Director, New York City Aquarium

New York Naval Shipyard, Brooklyn, New York, Public Works Department. Visited 28 July 1964.

Mr. Joseph H. Finger, Director Design Division

Mr. Virgil Blancato, Design Engineer

Public Works Office, U. S. Naval Submarine Base New London, Groton, Connecticut. Visited 29 July 1964.

CDR Dunham, USN, Public Works Officer

Mr. Fred Spence, Special Assistant to Public Works Officer

Mr. Robert Russ, Director Maintenance and Control Division

Lamont Geological Observatory, Palisades, New York. Visited 30 July 1964.

Dr. Paul R. Burkholder, Director Marine Biology Program

Dr. Pfister, Biophysicist

Dr. Bunce

Dr. Allen W. H. Bé, Director Biological Oceanography

Atlantic Division, Bureau of Yards and Docks, Norfolk, Virginia. Visited 3-5 August 1964.

Mr. George L. Sims, Jr., Special Assistant for Applied Biology (host for visit to Atlantic Division)

Mr. Charles M. [illegible]nedy, Director of Maintenance Division

Mr. C. Morrison, Manager of Maintenance Engineering Branch

Mr. C. A. Keefer, Cathodic Protection Engineer

Mr. William R. Mark, Jr., Sanitary Engineer

Mr. Rupert L. Cox, Chemist, Assistant to Sanitary Enginee[illegible]

Mr. H. D. McMurtry, Staff Conservationist and Natural Resources Management

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U. S. Navy Public Works Center, Norfolk, Virginia. Visited 4-5 August 1964.

CAPT. T. E. Barnett, USN, Commanding Officer

LT. Morrison, Assistant Operations Officer, and Exchanger Officer from the Navy of Canada (host for visit to the Public Works Center)

Mr. C. F. Campen, Head of Maintenance Control Division

Mr. R. E. Ethridge, Head of Inspection Division

Mr. J. R. Scott, an inspector in above division

Mr. M. E. Nelson, Master Mechanic, PWC, Utilities

Mr. W. D. Lindsay, Quarterman Waterfront Construction

University of Southern California, Los Angeles, California. Visited 6 October 1964.

Dr. John L. Mohr, Professor of Biology (host)

Dr. Norman Kharasch, Professor of Organic Chemistry

Dr. Leslie A. Chambers, Director, Allan Hancock Foundation, Professor of Biology, author

Dr. Arvan Fluharty, Assistant Professor, Biochemistry

Dr. Stephen E. Geiger, Research Fellow, Biology

Dr. Paul Saltman, Professor Biochemistry

Dr. Paul R. Saunders, Head, Biological Sciences Department, Professor of Biology, Director of Marine Program

Dr. Jay M. Savage, Director of Systematic Program, Professor of Biology, Co-principal Investigator on Midwater Trawl Survey of Catalina Channel, and on Antarctic investigations

Dr. Richard Tibby, Professor of Biology (Oceanography)

District Public Works Office, Eighth Naval District, New Orleans, Louisiana. Visited 21-23 October 1964.

Mr. H. C. Secrest, Special Assistant for Applied Biology (host)

CAPT. W. M. Gustafson, USN, District Public Works Officer

CDR A. M. Pollard, USN, Assistant District Public Works Officer for Facilities Management

Mr. W. J. Collins, Jr., Director Maintenance Division

LT. CDR B. E. Stultz, USN, Management Coordination Officer

Mr. R. J. Franz, Corrosion Engineer

Mr. C. A. Cranford, District Sanitary Engineer

Mr. W. A. Gehrke, Supervisory Maintenance Engineer

Mr. C. S. Ingram, Engineer Technician

Headquarters Support Activity, New Orleans, Louisiana. Visited 22 July 1964.

LTJG F. C. Justice, USN, Public Works Officer

Ensign J. L. Scherling, Assistant Public Works Officer

Mr. M. L. Mills, Pest Control Equipment Operator

Industrial Manager, USN, Eighth Naval District, New Orleans, Louisiana. Visited 22 July 1964.

Mr. R. V. LaBarre, Industrial Specialist

Todd Shipyard Corporation, New Orleans Division, New Orleans, Louisiana. Visited 22 July 1964.

Mr. Walker B. Coleman, Jr., Plant Engineer

Southern Forest Experiment Station, Forest Service, U. S. Department of Agriculture, New Orleans, Louisiana. Visited 23 July 1964.

Dr. Arthur F. Verrall, Principal Pathologist

Sierra Club, 1050 Mills Tower, San Francisco. A representative of the Club was visited 8 December 1964 at Santa Barbara.

Mr. Frederick Eissler, Member Executive Board, Conservation Chairman Los Padres Chapter, Santa Barbara

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University of California, Letters and Science Extension, Berkely, California. One of the authors attended three day conference, The Biology of Marine Microorganisms, 21-23 December 1964.

Dr. Claude E. ZoBell, guest conference leader, Professor Marine Microbiology, Scripps Institute of Oceanography, San Diego, California

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U. S. Naval Construction Battalion Base Unit, Port Hueneme, California. Visited 25 January 1965.

LTJG J. D. Kunz, USN, Training Officer, Seabee Technical Assistance Teams

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General Electric Company. Two representatives of the company visited the Laboratory on 26 February 1965.

Dr. Walter L. Robb, General Electric Research Laboratory, Schenectady, New York. Inventor of membrane process for regenerating air

Mr. Phil A. Dee, General Electric Company, Pacific Range Programs, Santa Barbara, California

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Figure 1. Fungus decay in cold-storage building.
(Naval Air Station, Corpus Christi, 1963)

Figure 2. Building whose roof failed to shed water.
(Naval Air Station, Willow Grove, 1958)

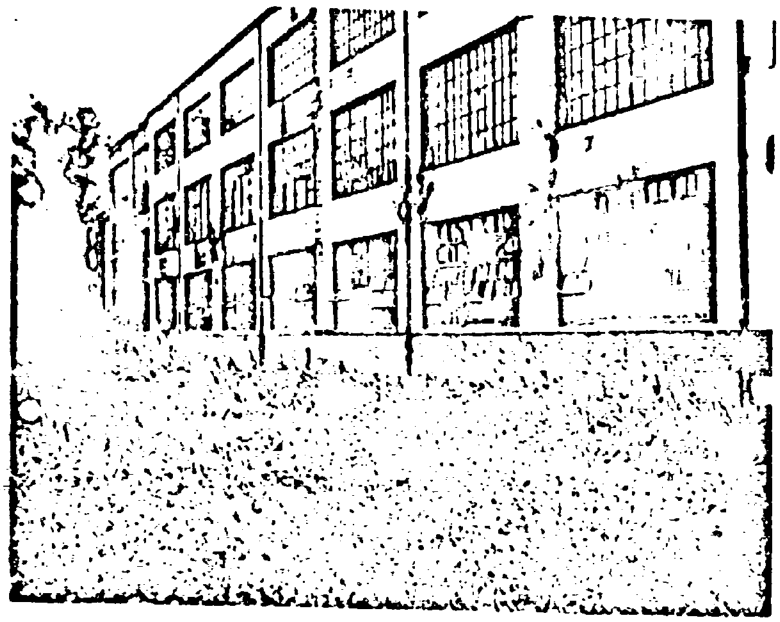


Figure 3. Navy-owned plate shop leased to shipyard.
(Todd Shipyard Corp., New Orleans, 1962)

Figure 4. Decaying window frames of plate shop.
(Todd Shipyard Corp., New Orleans, 1962)

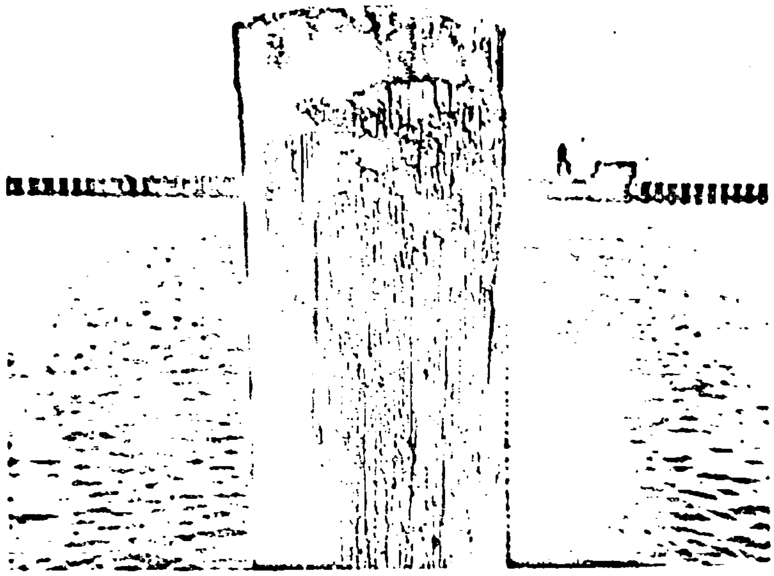


Figure 5. Fungus decay in 7 years on Greenheart pile.
(Naval Ammunition Depot, Earle, 1961)

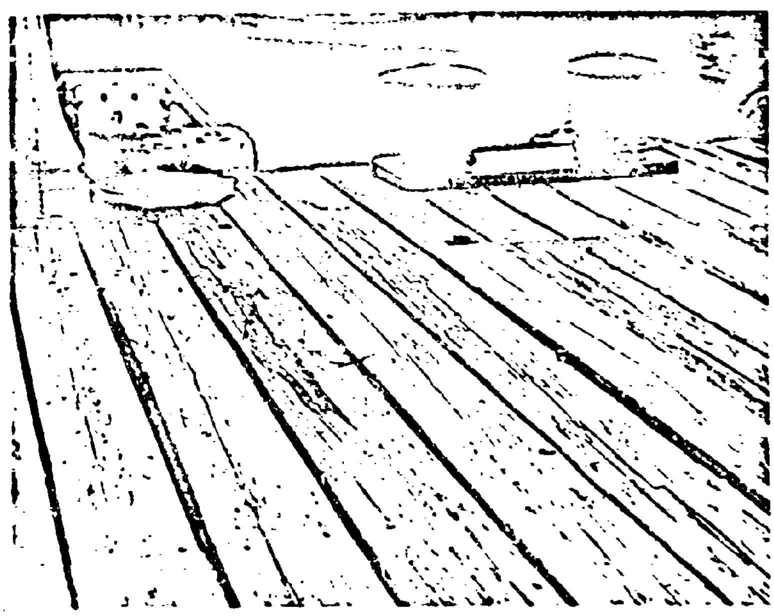


Figure 6. Decaying deck of submarine pier.
(Naval Submarine Base, Groton, 1961)

Figure 7. Guard rail damaged by Limnoria and fungi. (Fleet Training Center, San Diego, 1963)

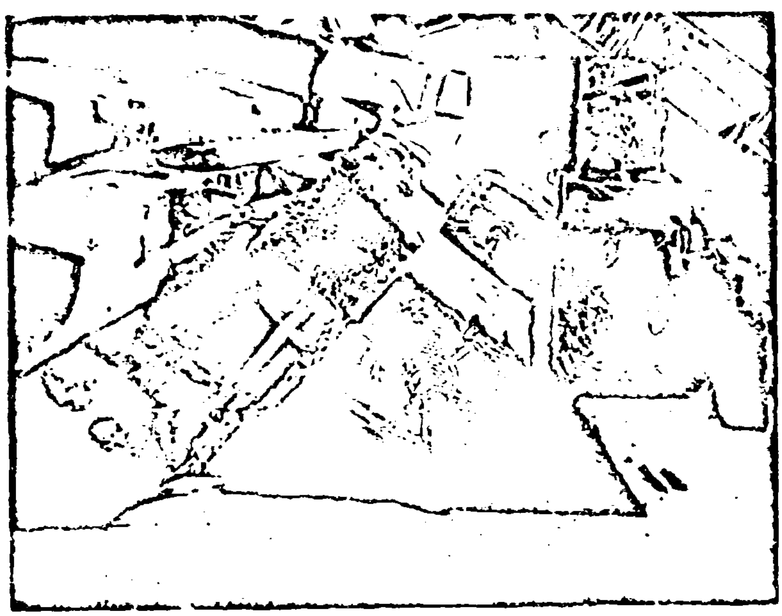


Figure 8. Limnoria attack on timbers of 13 year old pier. (Naval Civil Engineering Laboratory, 1955)

Figure 9. Deteriorating asphalt on railroad pier.
(Naval Ammunition Depot, Earle, 1963)

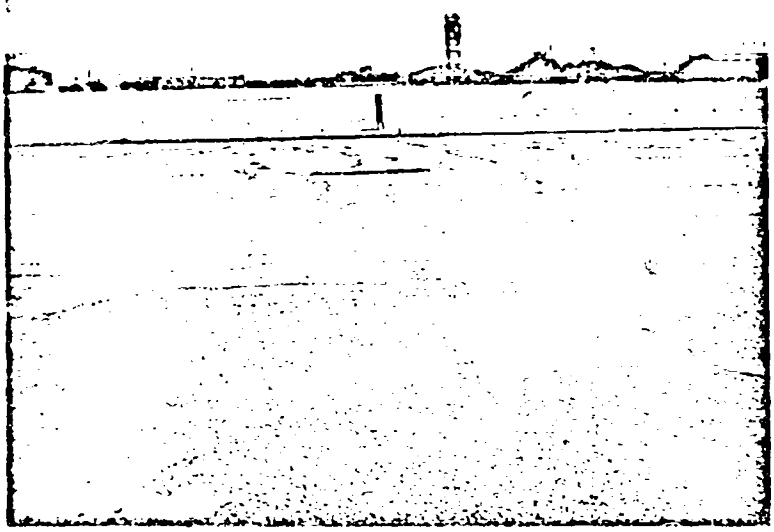


Figure 10. Deteriorating asphalt on airfield runway.
(Marine Corps Air Station, Yuma, 1964)

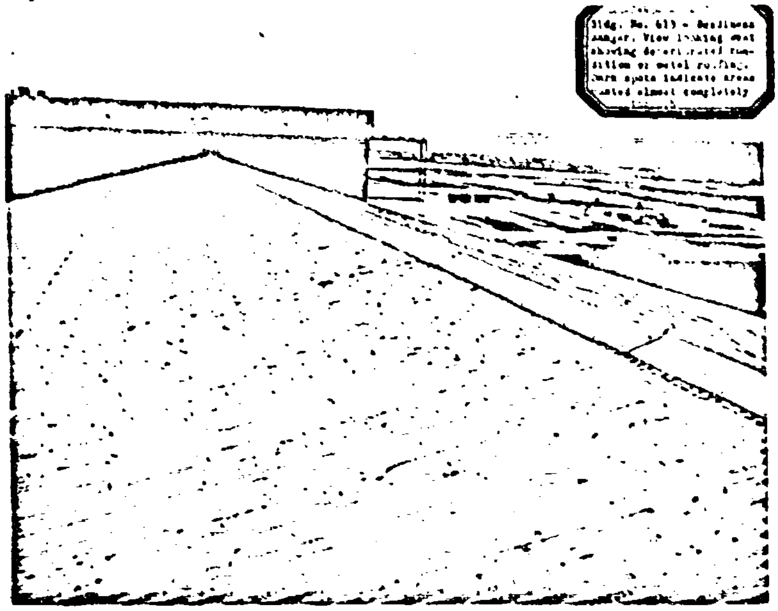


Figure 11. Metal roof perforated by corrosion.
(Naval Station, Newfoundland, 1962)

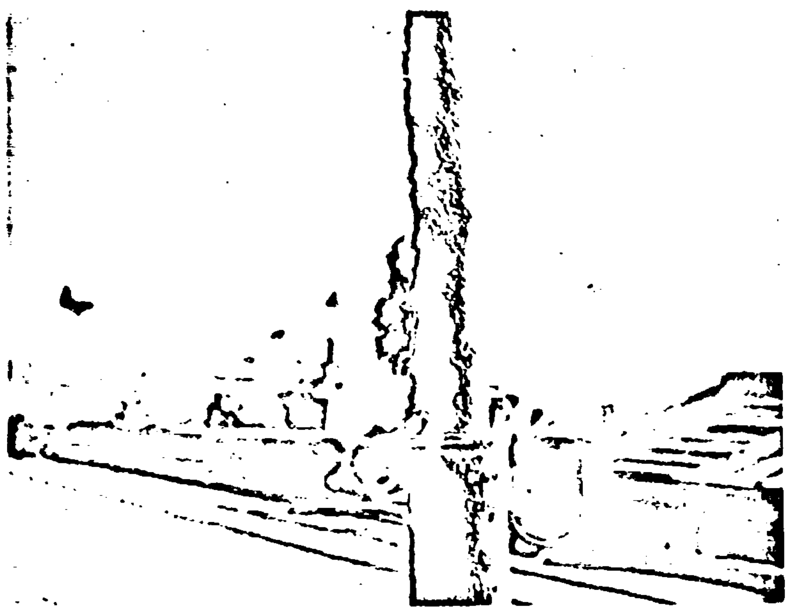
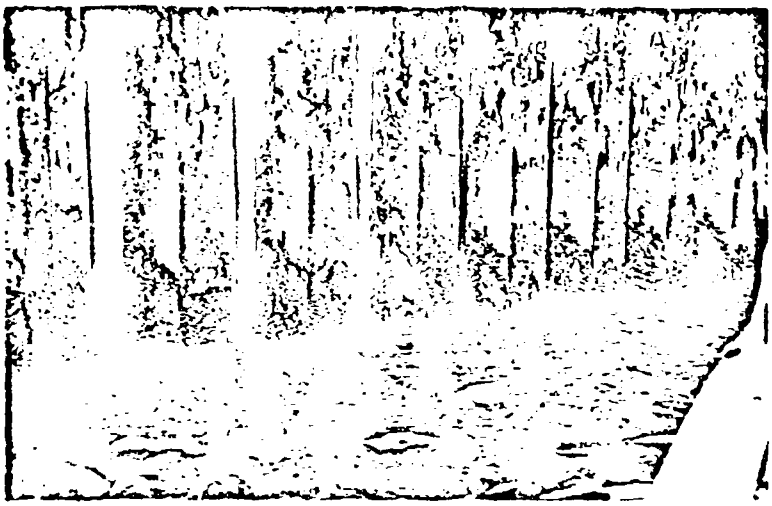


Figure 12. Metal light pole exposed to ocean spray.
(Naval Shipyard, Norfolk, 1958)

Photograph 15. "C" Section Sta. 13+40 to 21+17

Figure 13. Loss of earthen fill by damaged bulkhead. (Naval Air Station, New York, 1963)



Photograph 1[illegible]. "C" Section Sta. 13+40 TO 21+17

Figure 14. Corroding bulkhead in need of repair. (Naval Air Station, New York, 1963)

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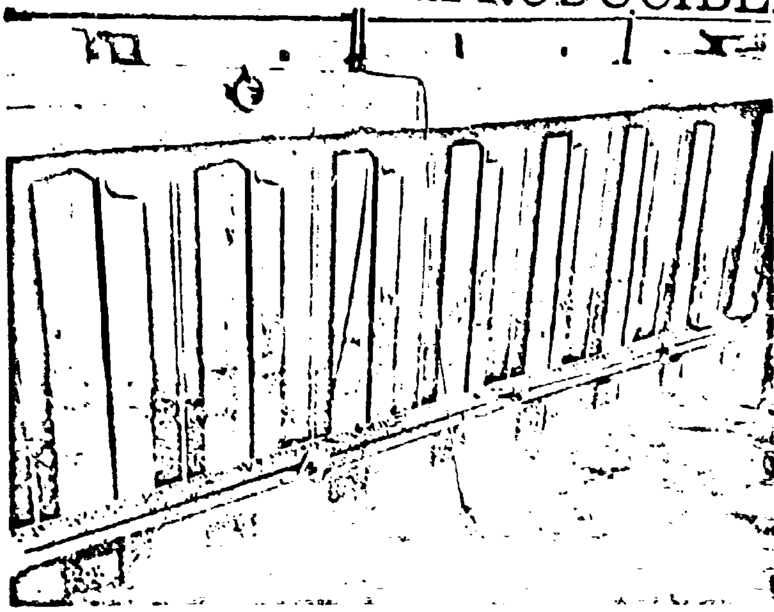

Figure 15. Bulkhead 3 years before hurricane Donna.
(Naval Air Station, Norfolk, 1956)

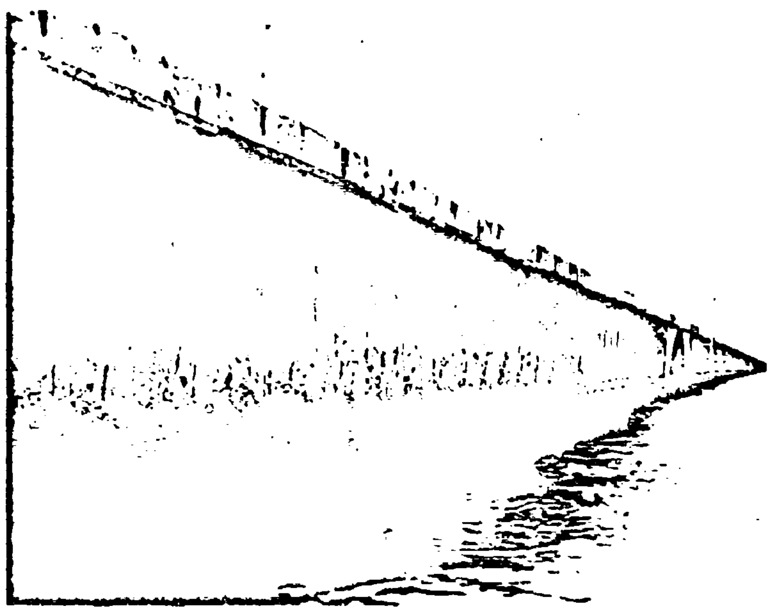

Figure 16. Bulkhead immediately prior to hurricane.
(Naval Air Station, Norfolk, 1959)

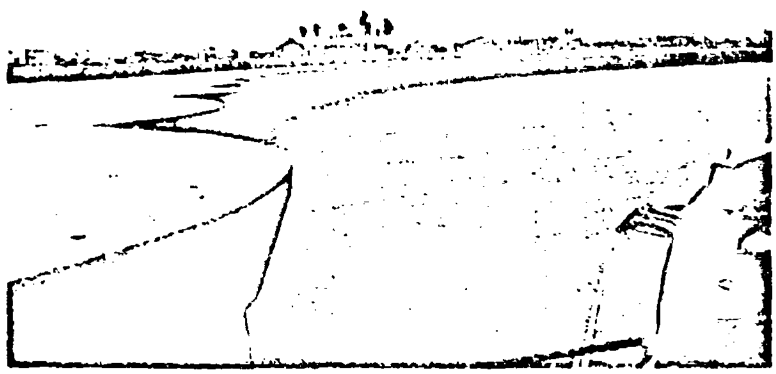

Figure 17. Concrete decked steel breakwater.
(Naval Air Station, Corpus Christi, 1959)

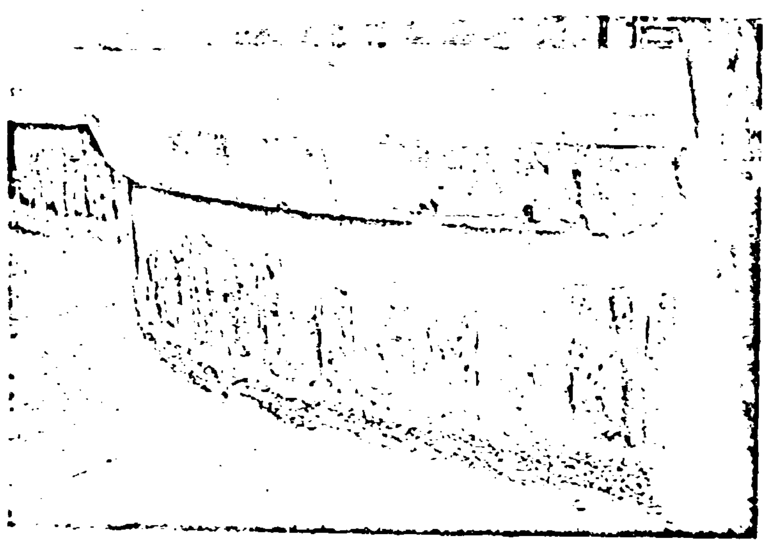

Figure 18. Corrosion of sheet piling on breakwater.
(Naval Air Station, Corpus Christi, 1959)

Figure 19. Concrete pier exhibiting sulfate attack.
(Naval Air Station, Norfolk, 1959)

Figure 20. Above-water portion of concrete pier.
(Naval Air Station, Norfolk, 1959)

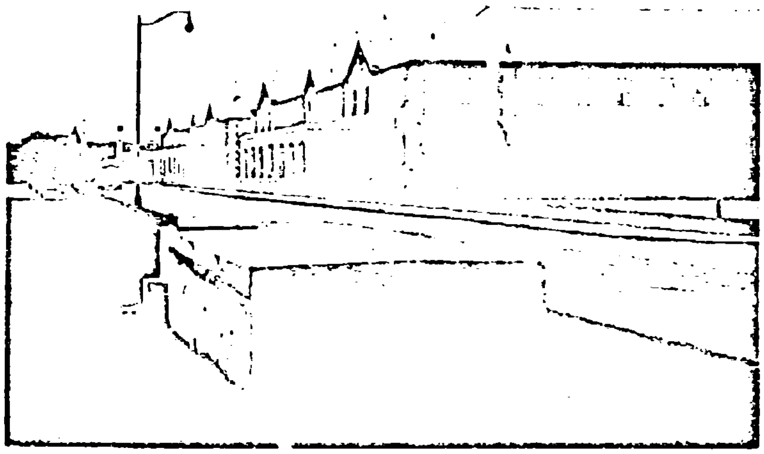

Figure 21. Concrete barracks constructed in 1959.
(Naval Station, Bermuda, 1964)

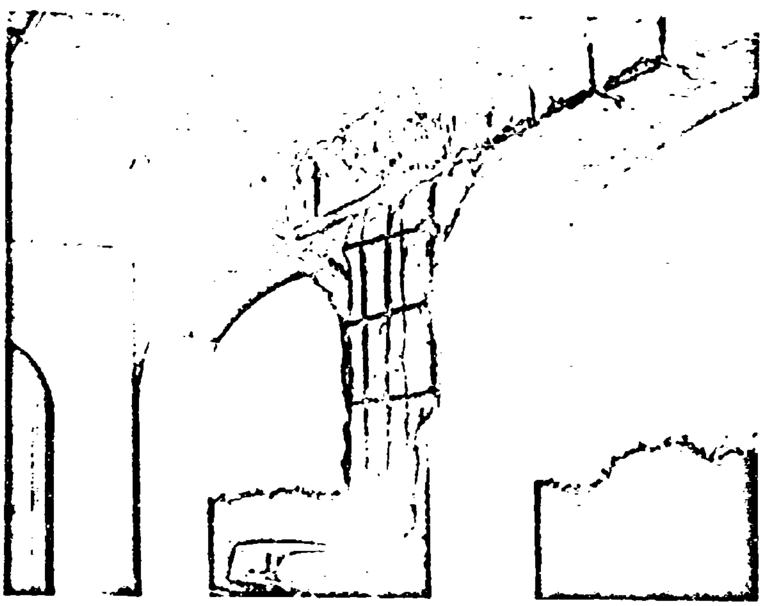

Figure 22. Spalling concrete on barracks porch.
(Naval Station, Bermuda, 1964)

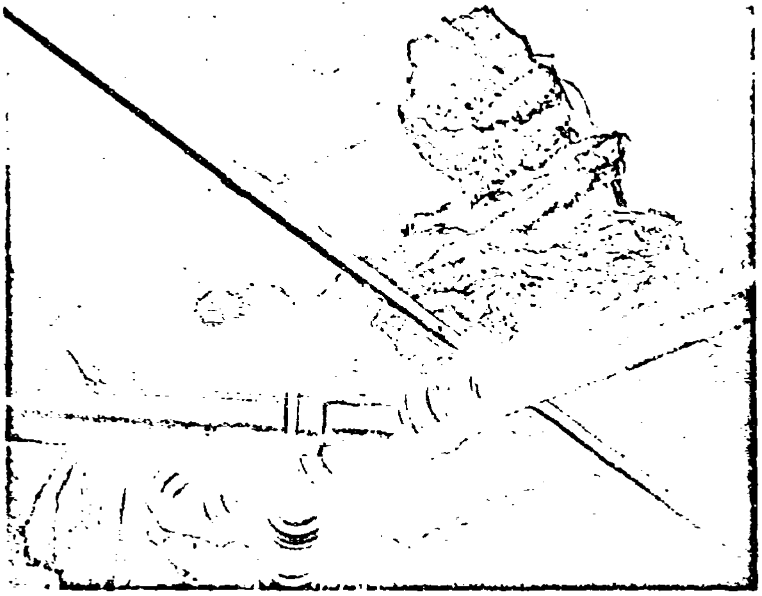

Figure 23. Spalling around pipes on barracks interior.
(Naval Station, Bermuda, 1964)

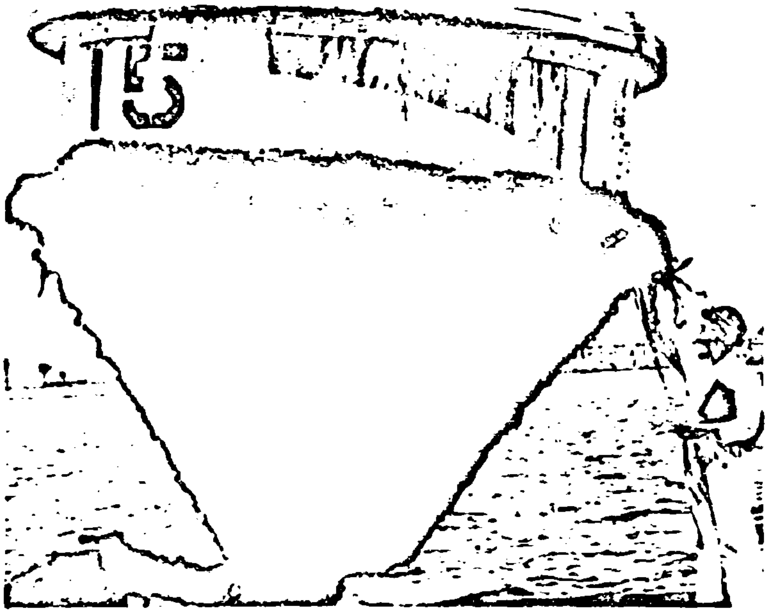

Figure 24. Mooring buoy hoisted from water for cleaning.
(Public Works Center, San Diego, 1964)

Figure 25. Inflatable causeway in harbor 15 months.
(Naval Civil Engineering Laboratory, 1962)

Figure 26. Causeway damaged by removal of fouling.
(Naval Civil Engineering Laboratory, 1962)

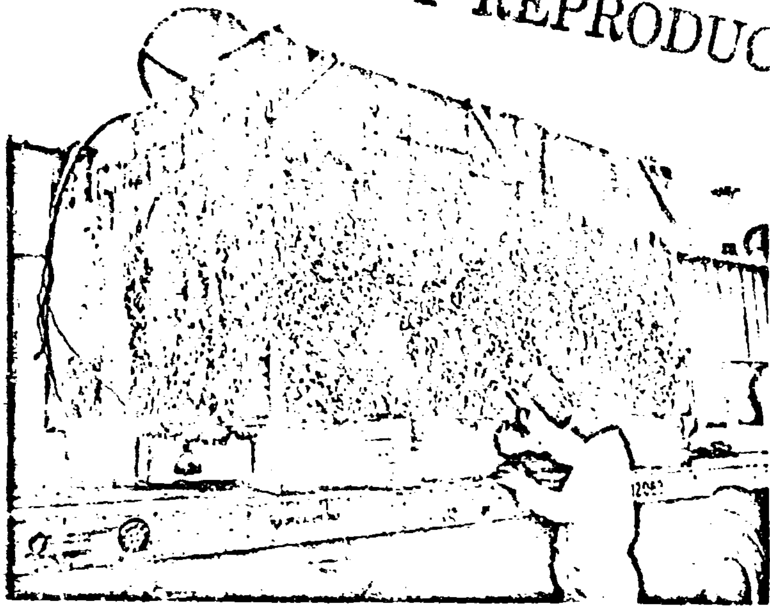

Figure 27. Pontoon anchored 80 miles from shore.
(Naval Civil Engineering Laboratory, 1964)

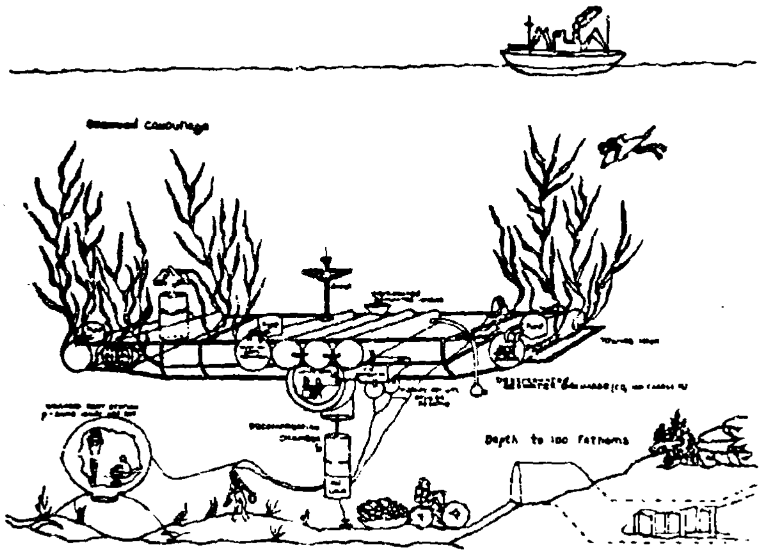

Figure 28. Conceptual view of Seabees working undersea.
(Naval Civil Engineering Laboratory, 1965)

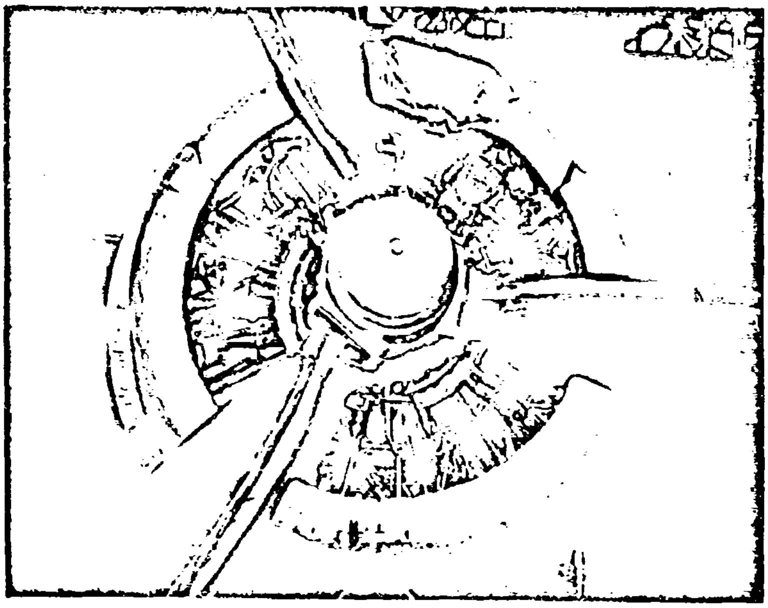

Figure 29. Airplane damaged in encounter with sea gulls.
(Naval Air Station, New York, 1957)

Figure 30. Sea gulls removed from airplane engine.
(Naval Air Station, New York, 1957)

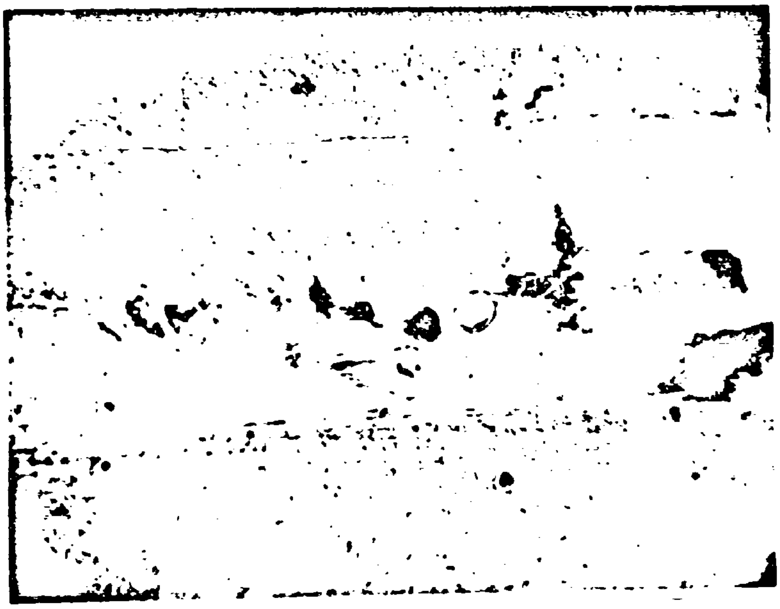

Figure 31. Marine borers in wood exposed in deep ocean. (Naval Civil Engineering Laboratory, 1964)

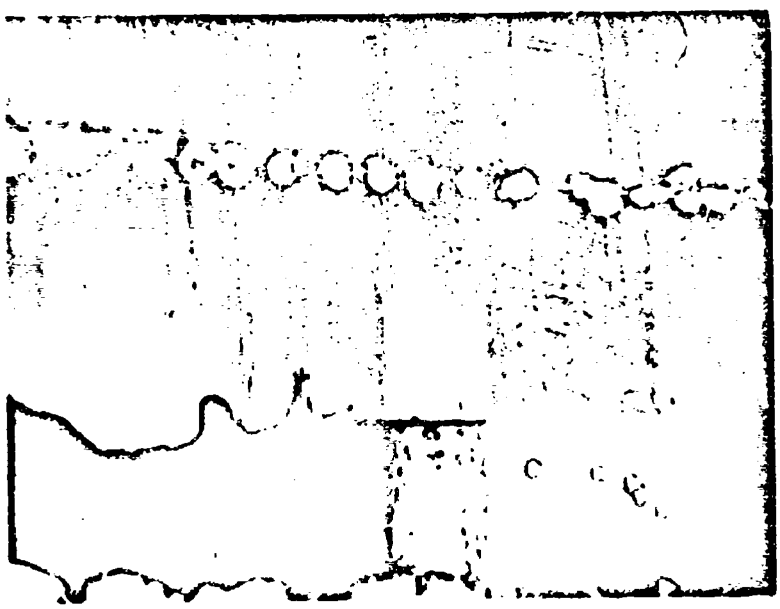

Figure 32. Borer damage to acrylic resin in deep ocean. (Naval Civil Engineering Laboratory, 1965)

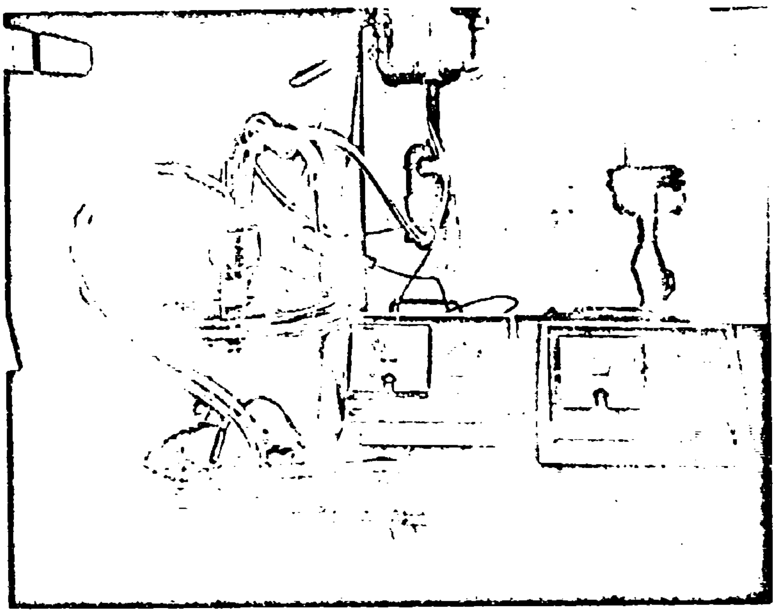

Figure 33. Rats maintained on air removed from sea water. (Naval Civil Engineering Laboratory, 1965)

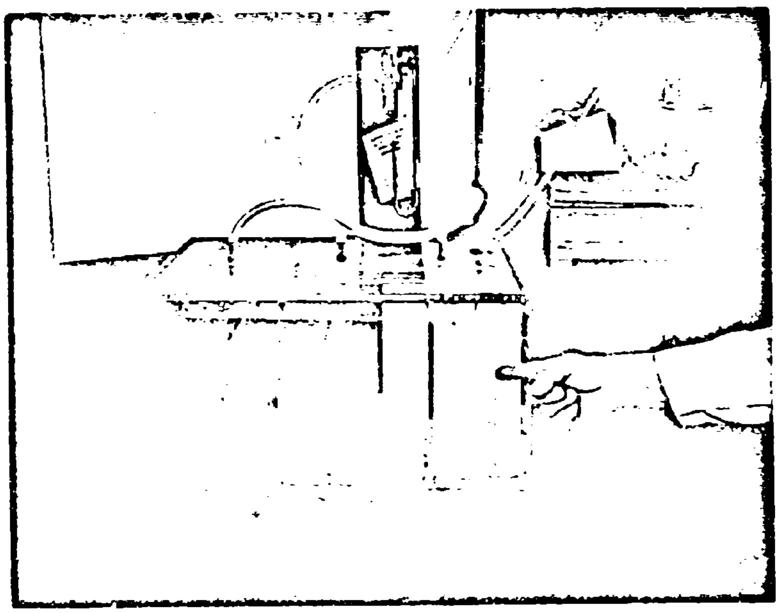

Figure 34. Tank for separating mixture of air and water. (Naval Civil Engineering Laboratory, 1965)

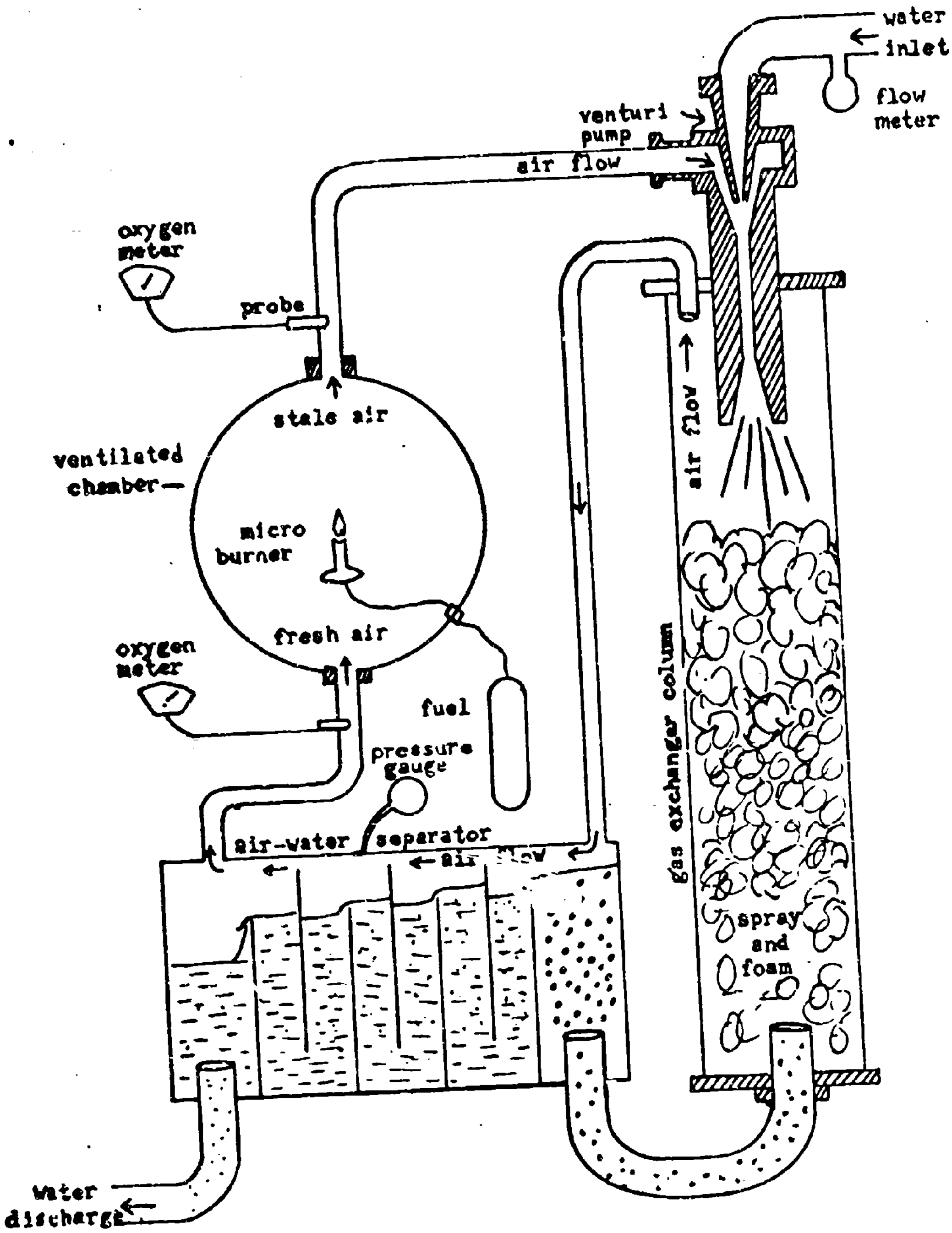

Figure 35 Diagramatic sketch of chamber ventilated by means of a venturi gas exchanger